IMES DISCUSSION PAPER SERIES

Broad-Perspective Review Series

On the Zero-Inflation Norm of Japanese Firms

Kakuho Furukawa, Yoshihiko Hogen, Kazuki Otaka, and Nao Sudo

Discussion Paper No. 2024-E-15

IMES

INSTITUTE FOR MONETARY AND ECONOMIC STUDIES

BANK OF JAPAN

2-1-1 NIHONBASHI-HONGOKUCHO
CHUO-KU, TOKYO 103-8660
JAPAN

IMES Discussion Paper Series 2024-E-15
November 2024

On the Zero-Inflation Norm of Japanese Firms

Kakuho Furukawa*, Yoshihiko Hogen, Kazuki Otaka***, and Nao Sudo******

Abstract

From the mid-1990s, when Japan's inflation rate plummeted to a low level, until recently, an increasing portion of firms in the service sector ceased to change their prices. This paper studies the causes of this phenomenon, often referred to as the "zero-inflation norm," and argues that the norm was generated by a fall in the inflation rate and a rise in menu costs. First, using the source data of Japan's official consumer price index (CPI), we document that the emergence of the norm went hand-in-hand with the decline in the inflation rate. Next, we extend the menu cost model of Nakamura and Steinsson [2008] and show that it is able to explain a part of the emergence and disappearance of the norm by changes in the inflation rate, but we emphasize the importance of menu costs for bringing the model close to the data. More precisely, with large and asymmetric menu costs for upward and downward price changes, as implied by the Japanese price data, the model explains about half of the norm. With modest menu costs as implied by the U.S. data, however, the model barely generates the norm at all. Lastly, we study the possibility that model parameters might have changed during the time of the norm. We find that in order for the model to explain the remaining portion of the norm as well as the observed developments in the size of price changes, menu costs and the curvature of the demand curve should have risen, with the former playing a quantitatively important role. Increases in implied menu costs occurred very noticeably in the service sector and less so in the goods sector, lagged the inflation rate decline, and were pronounced for items that saw low inflation rates during the mid-1990s, suggesting the possibility that prevailing low inflation rates and low frequencies of price changes made firms change prices even less frequently than what the standard menu cost model would imply.

Keywords: micro price dynamics; menu costs; kinked demand; strategic complementarity

JEL classification: E3, E31, E5

* Deputy Director, Research and Statistics Department (currently, Financial System and Bank Examination Department), Bank of Japan (E-mail: kakuho.furukawa@boj.or.jp)

** Director, Research and Statistics Department, Bank of Japan (E-mail: yoshihiko.hougen@boj.or.jp)

*** Director, Research and Statistics Department, Bank of Japan (E-mail: kazuki.ootaka@boj.or.jp)

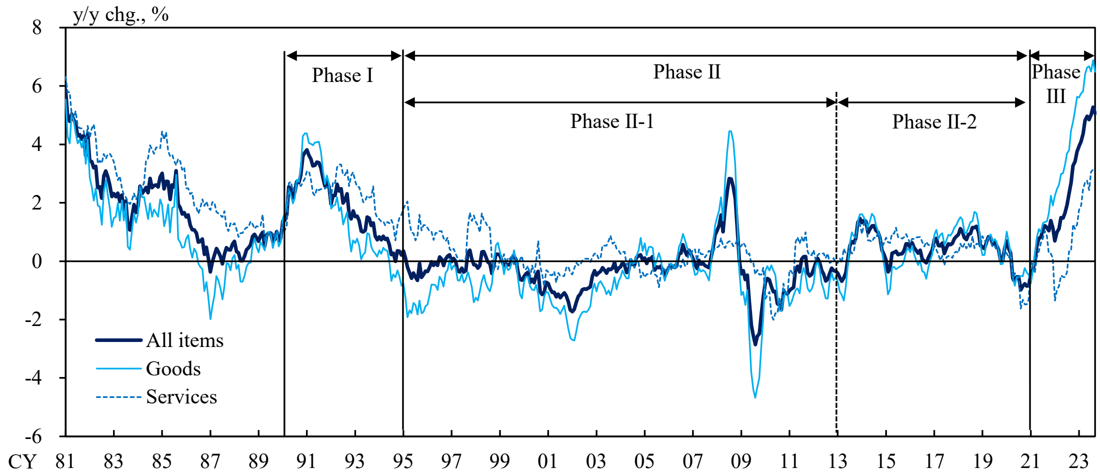
**** Deputy Director-General, Institute for Monetary and Economic Studies (currently, Financial System and Bank Examination Department), Bank of Japan (E-mail: nao.sudou@boj.or.jp)

The authors would like to thank Kosuke Aoki, Ichiro Fukunaga, Takeo Hoshi, Ryo Jinnai, Paolo Pesenti, Toyoichiro Shirota, participants of the 2024 BOJ-IMES conference and 2024 SWET, and Bank of Japan staff for their helpful comments and discussions. The Statistics Bureau of the Ministry of Internal Affairs and Communications provided data from the Retail Price Survey. The figures and analysis in this paper are based on the authors' own calculations. Any remaining errors are attributable to the authors. The views expressed in this paper are those of the authors and do not necessarily reflect the official views of the Bank of Japan.

1 Introduction

Until the recent surge in inflation following the end of the pandemic, the Japanese economy had seen a quarter century of low inflation. After the bursting of the bubble economy in the early 1990s, the inflation rate, measured by the consumer price index (CPI), declined from 4 percent in 1991 to 0 percent in 1995 and remained around this low rate for more than 25 years (Figure 1). One noticeable feature of firms' price-setting behavior during this low inflation period is the increase of items without changes in price, often referred to as the "zero-inflation norm." Figure 2 shows the distribution of item-level inflation rates for 1992, 2005, and 2023 on the left, and the time path of the share of zero-inflation items in the CPI from 1990 to 2023 on the right. The portion of items that exhibit zero inflation increased from 19 percent in 1992 to 46 percent in 2005, mostly in the service sector. The share remained at an elevated level until the late 2010s, when it started to decline gradually.

(Figure 1) CPI inflation in Japan



Notes: The impact of temporary factors such as the consumption tax hike is removed by subtracting the rate of change in the corresponding month. Data exclude fresh food, electricity, manufactured and piped gas, water charges, and housing rent.
Source: Ministry of Internal Affairs and Communications.

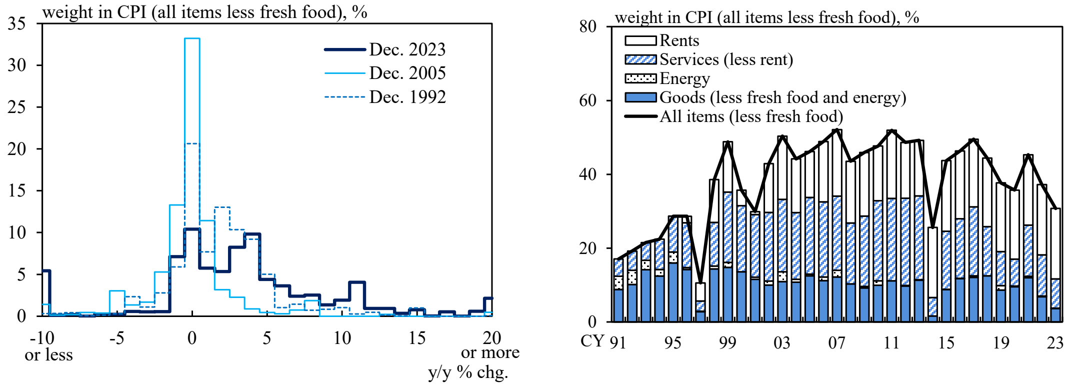
The zero-inflation norm is often interpreted as "an implicit understanding among sellers and buyers (Watanabe and Watanabe [2018])" that prices will not be revised each year[1] and overcoming this norm has been referred to as a key challenge for the Bank of Japan in achieving price stability. For example, Kuroda [2022a] states that "the primary reason for being unable to achieve the price stability target of 2 percent, …, is that this 'zero percent anchoring' of inflation expectations — in other words, 'zero-inflation norm' — has been

[1] As discussed in Watanabe and Watanabe [2018] and Ichiue *et al*. [2019], the concept of an inflation norm goes back to the early discussion of Okun [1981] and Schultze [1981].

extremely persistent."

(Figure 2) Share of zero-inflation items

Distribution of price changes (CPI all items less fresh food and rent) | Share of zero-inflation items



Notes: In the left panel, the increment of the intervals is 1 percentage point, except for the outer bins. The right panel shows the weight of the items in the CPI for which the year-on-year price change is within ±0.5%. There were consumption tax hike in 1997, 2014, and 2019, the effects of which are shown in the right panel.
Source: Ministry of Internal Affairs and Communications.

In this paper, we focus on the zero-inflation norm and explore what has caused the norm to emerge. Because the zero-inflation norm emerged mainly in the service sector, our analysis focuses on the developments of price changes in the service sector throughout the paper. First, we use city-level microdata of consumer prices, the source data of the official consumer price index (CPI) in Japan, from 1990 to 2023, and document developments of the intensive and extensive margins of prices[2] over time. For analytical purposes, as shown in Figure 1, we divide our sample period into three phases: Phase I, the high inflation period from 1990 to 1994; Phase II[3], the low inflation and deflation period from 1995 to 2020; and Phase III, the recent high inflation period from 2021 to 2023, and study changes in price dynamics over the phases. We document several observations regarding the norm. The first and most important observation is that the frequency of price changes is positively related to the inflation rate. That is, the norm emerged when the aggregate service inflation rate fell to a low value. This observation holds not only at the aggregate level but also at the item-level. Declines in the frequency of price changes from Phase I to II are pronounced among items that saw a larger decline in their inflation rates. Indeed, these observations somewhat contrast with the theoretical prediction made by the standard menu cost models.

[2] Inflation is the product of the intensive and extensive margins, where the intensive margin is the average size of price changes and the extensive margin is the fraction of items with price changes (Klenow and Kryvtsov [2008]).

[3] We further divide Phase II into Phase II-1 (1995-2012) and II-2 (2013-2020) since earlier works find that the series of monetary policies introduced after 2013, such as Quantitative and Qualitative Monetary Easing (QQE) and Yield Curve Control (YCC), were effective in raising inflation (Bank of Japan [2021], Michaelis and Watzka [2017]).

For example, Alvarez *et al.* [2019] point out that in a neighborhood of a zero inflation rate, the frequency of price changes becomes unresponsive to the inflation rate because the frequency of price increases approaches the frequency of price decreases, with the two effects offsetting each other. The second observation is that the zero-inflation norm emerged in Phase II as a consequence of asymmetric developments of the frequency of price increases and price decreases. The frequency of price increases fell noticeably from Phase I to II and rose again noticeably from Phase II to III, while the frequency of price decreases rose modestly from Phase I to II and declined modestly from Phase II to III. The zero-inflation norm in Phase II emerged because changes in the frequency of price increases dominated those in the frequency of price decreases. Similar observations hold at the item level, particularly in the service sector. In addition to these two observations, we document that while the frequency of price changes fell from Phase I to II and rose from Phase II to III, the size of price changes increased over the phases, generating a weak but negative correlation between the frequency and size of price changes. These three observations also hold partly for the goods sector, although only modestly so.

Next, we construct a set of simple menu cost models, extending the model of Nakamura and Steinsson [2008], and examine if they are able to account for these observations. To this end, we calibrate our model parameters using Japanese price data during Phase I, feeding the actual inflation rate into the models and computing the time path of the frequency of price changes from the models. Our models with the actual inflation rates generally explain roughly a half of the zero-inflation norm as they predict an asymmetric response of changes in frequency of price increases and price decrease. Our simulation exercises underscore the importance of the role of menu costs for the emergence of the norm. The menu costs calibrated to Japan's price data during Phase I are larger than those calibrated to the U.S. price data and costs associated with price decreases are larger than those associated with price increases. When menu costs are sizable and asymmetric as in Japan during the early 1990s, the frequency of price increases falls substantially while the frequency of price decreases increases only modestly following a decline in the aggregate inflation rate, resulting in the emergence of the zero-inflation norm. In other words, characteristics of menu costs amplify the effects of changes in the inflation rate. In contrast, when the models are simulated with menu costs that are calibrated to U.S. data, namely with small and symmetric menu costs, the zero-inflation norm barely emerges at all.

Lastly, we study what other factors could account for the remaining half of the emergence of the zero-inflation norm. We explore the possibility of changes in model parameters. We allow the model's parameter values to change over time and estimate the time path of parameter values consistent with the actual movements of the frequency and size of price changes. We find that implied parameter values for the menu costs and the degree of kinkedness of households' demand curve, i.e., the curvature of households' demand curve, became larger from Phase I to II, contributing to the emergence of the norm in Phase II. We find that quantitatively a rise in menu costs plays an important and large role. One reason why this exercise implies larger menu costs in Phases II and III than those in Phase I is the empirical observation that the size of price changes became larger over the three phases, which is consistent with the prediction of our menu cost models with increases in menu costs. Regarding the implied menu cost series, we also note three observations. First, increases in implied menu costs occur saliently in the service sector (and generally not in the goods sector). Second, the increases follow a decline in the inflation rate with a lag of two-to-three years. Third, the increases are salient for items that see a decline in their inflation rates to a low rate in Phase II. These observations are, to some degree, consistent with the view that there have been changes in perceptions or social norms of price changes among firms and households since low inflation rates started to prevail and that firms' heightened concerns about losing customers has generated the norm.[4,5,6]

Related Literature

Most importantly, our paper is related to the enormous amount of research on Japan's chronic deflation since the mid-1990s from various perspectives, ranging from potential reasons for why the inflation rate was weak for a prolonged period of time to the coefficient of the price and wage Philips curves, or to inflation expectations formation. A non-exhaustive list of these works includes, Nishizaki, Sekine, and Ueno [2014], Watanabe and Watanabe [2018], Ichiue *et al.* [2019], Aoki, Ichiue, and Okuda [2019], Kaihatsu, Katagiri, and Shiraki [2022], Kuroda [2022a, b], and Watanabe [2023]. To the best of our knowledge, our paper is the first paper that quantifies the impact of potential factors leading to the emergence of the zero-inflation norm, such as the trend inflation rate, changes in the degree

[4] While the standard model does not assume menu costs vary over time, the menu costs in principle could go up and down when firms' non-physical costs are considered. For example, Zbaracki *et al*. [2004], examining the source and size of menu costs using data from a large U.S. industrial manufacturer and its customers, estimate various types of non-physical menu costs that depend on characteristics of firms and their customers. In particular, they argue that there are three types of managerial costs—information gathering, decision making and communication costs, and two types of customer costs—communication and negotiation costs.

[5] Aoki, Ichiue, and Okuda [2019] theoretically show that when households form a prior belief that the inflation rate is persistently low, the curvature of the demand curve increases.

[6] Fukunaga, Kido, and Suita [2024] discuss how Japanese firms have been facing global deflationary shocks over the years. More recently, the frequency of price increases for services has increased since 2022, driven by global shocks related to commodity price increases that spread to items such as food and services.

of kinkedness of the demand curve, and menu costs, using a standard menu cost model.[7] It is worth noting, however, that our study complements rather than competes with the existing studies that address potential causes of the zero-inflation norm, since causes studied in our work have already been discussed in these studies though not quantified.

In addition, our paper is related to two strands of studies that are connected. The first strand is the extensive literature on micro-pricing, in particular, that focusing on Japan, including Sudo, Ueda, and Watanabe [2014], Abe and Tonogi [2010], Mizuno, Nirei, and Watanabe [2010]. Since the early 2000s, progress has been made in uncovering firms' micro-pricing behavior by analyzing detailed microdata from CPI sources in advanced economies.[8] Our study differs from existing works in that it focuses on the zero-inflation norm and therefore focuses on the extensive margin of service items, contrasting with studies that focus on goods exclusively, such as Sudo, Ueda, and Watanabe [2014]. The second strand is research that uses menu cost models in aiming to account for empirical regularities of price dynamics found by micro-price analyses. These include, for example, Golosov and Lucas [2007], Nakamura and Steinsson [2008], Alvarez *et al.* [2019], Karadi and Reiff [2019], and Blanco *et al.* [2024]. Alvarez *et al.* [2019] is close to our study as it explores theoretically and empirically the relationship between the frequency of price changes and the inflation rate using Argentinian data. They document that in a low-inflation environment, the frequency of price changes does not react to a change in the inflation rate, since the change in frequency of price increases and decreases almost offset each other. By contrast, we show theoretically that this may not hold true when menu costs are sizable and asymmetric and document empirically that the frequency of price changes is positively correlated with the inflation rate. In addition, our study differs from these works in that it focuses on the causes of the zero-inflation norm in Japan.

Structure of the Paper

Section 2 covers details of the data and methodology we use and documents the key observations. Section 3 uses an extended version of the standard menu cost model

---

[7] Our work is similar in terms of the focus and methodology to Kaihatsu, Katagiri, and Shiraki [2022], which analyzes the distribution of the inflation rate across items during the periods of high inflation (1982−1994) and low inflation (1995−2012). The authors document that distributions in the service sector have been weighted heavily around 0 percent and their dispersion has significantly narrowed over time. They then show that a decline in trend inflation is able to account for this observation using a multi-sector menu cost model. Our paper differs from their work in that it focuses on the zero-inflation norm rather than the distribution of inflation rates, and that it quantifies the role of various factors behind the zero norm.

[8] For the United States and Europe, see Bils and Klenow [2004], Dhyne *et al.* [2006], Klenow and Kryvtsov [2008], Nakamura and Steinsson [2008], and Gautier *et al.* [2023]. For Japan, see Ikeda and Nishioka [2007], Higo and Saita [2007], Kurachi, Hiraki, and Nishioka [2016], and Ueda [2024].

developed by Nakamura and Steinsson [2008] and provides an explanation for the observations. Section 4 uses the model to estimate the time path of model parameters that are consistent with the actual developments of the frequency and size of price changes. Section 5 concludes.

2 Data and Methodology

2.1 Data

To examine trends in the frequency and size of price changes in Japan, we use the city-level data underlying the CPI, called the *Retail Price Survey.* As shown in Appendix A, while there are some level differences, general movements of the series constructed from the city-level data are comparable to those constructed from store-level data.

2.2 Definition

The frequency of price changes (increases/decreases) of item i at time t ($f_{i,t}^{\pm}$) is defined as the share of locations where $p_{i,t}$ changed from the previous month,

$$f_{i,t}^{\pm} = \frac{\sum_c 1\left(p_{i,c,t} \gtrless p_{i,c,t-1}\right)}{N_i}, \tag{1}$$

where c is the set of cities where prices of item i is available, N_i is the number of such cities, and 1 is an indicator function for price change. Aggregation is done by aggregating all items using CPI weights (same for size). The size of price changes (increases/decreases) of item i at time t ($dp_{i,t}^{\pm}$) is defined as the average absolute price change (increases/decreases) for which prices changed from the previous month,

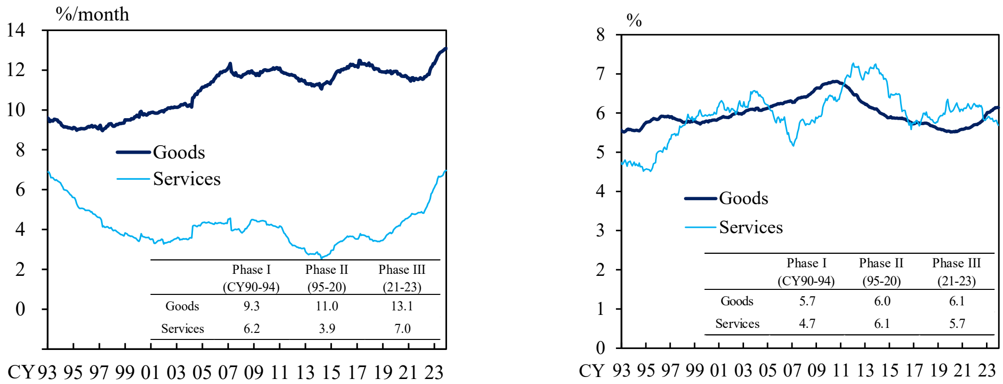
$$dp_{i,t}^{\pm} = \frac{\sum_{c\ s.t.\ p_{i,c,t} \gtrless p_{i,c,t-1}} \left|\log\left(p_{i,c,t}/p_{i,c,t-1}\right)\right|}{\sum_c 1\left(p_{i,c,t} \gtrless p_{i,c,t-1}\right)}. \tag{2}$$

2.3 Frequency and Size of Price Changes over Time

Figure 3 shows the long-run developments in the frequency and size of price changes (total of price increases and decreases) since the 1990s. Regarding the frequency, goods have followed an upward trend: 9.3 percent in Phase I (1990-1994), 11.0 percent in Phase II (1995-2020), and 13.1 percent in Phase III (2021-2023). The frequency of price changes for services declined after entering Phase II from 6.2 percent to 3.9 percent and remained at a low level until Phase III, when it rose to 7.0 percent. Regarding size, for goods there was a gradual and modest increase until around the period of the global financial crisis, followed by a decline in the subsequent period, except for recent years. For services, the size increased somewhat from the early 1990s, though with ups and downs, until the first half of the 2010s, and declined in the subsequent period.

(Figure 3) Frequency and size of price changes

Frequency of price changes | Size of price changes

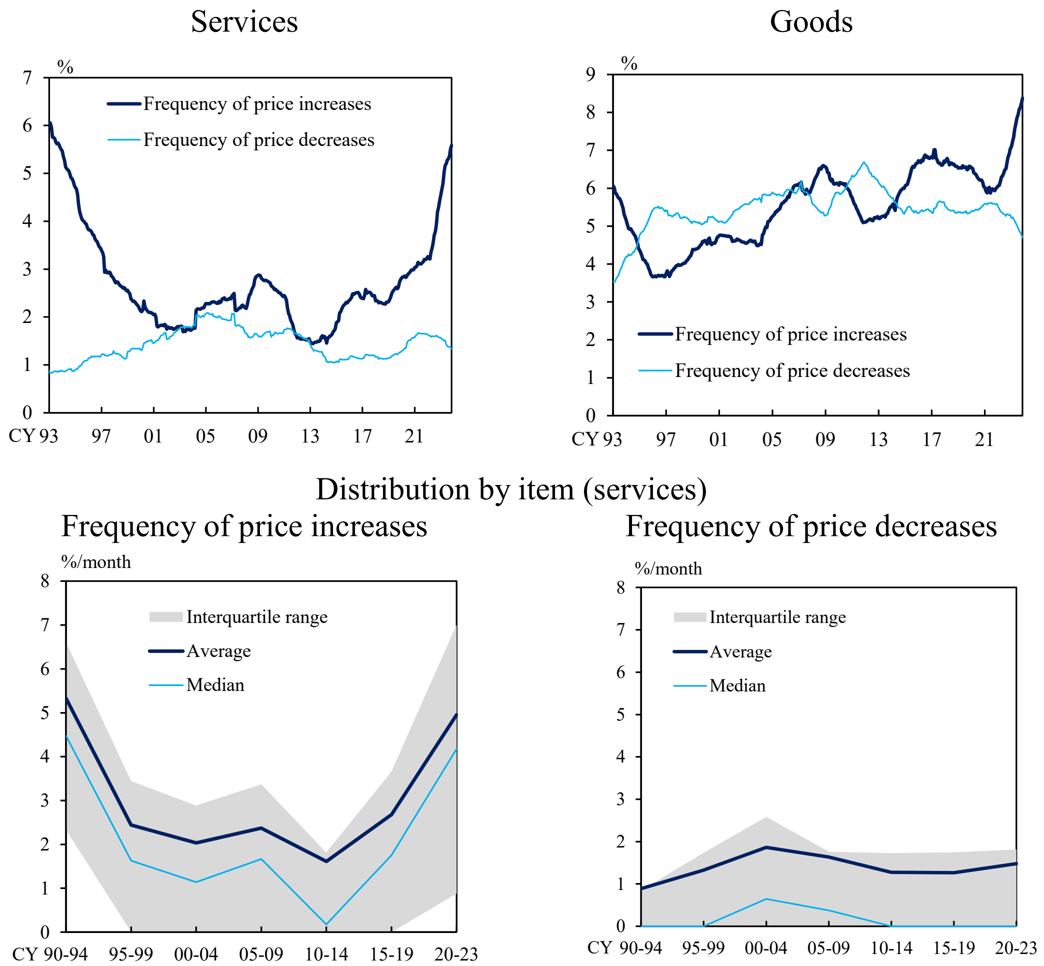


Notes: Regular prices. The data exclude fresh food, electricity, manufactured and piped gas, water charges, housing rent, and periods of consumption tax hikes. Backward 36-month moving average.
Source: Ministry of Internal Affairs and Communications.

Figure 4 separates the frequency of price changes by upward and downward price changes. Figure 4 (upper panels) shows the average of all items in services and goods. For services, the frequency of price increases falls noticeably from Phase I to II, remaining around that rate until the end of Phase III, while for price decreases, the frequency increases modestly from Phase I to Phase II and declines in Phase III. These observations indicate that an increase in zero-inflation items in services reflects the asymmetricity of changes in the frequency of upward and downward price changes. This observation contrasts with what has happened to the frequency of price changes for goods. For goods prices, while the frequency of price increases declined, the frequency of price decreases rose by around the same magnitude in the early 1990s, resulting in a minor rise in the frequency of price changes.

Figure 4 (lower panels) shows the distributions of frequency of price changes by item in services for both directions. A noticeable fall in the frequency of price increases from Phase I to II and a modest rise in the frequency of price decreases in the same periods can be seen for the average, median, and quartiles.

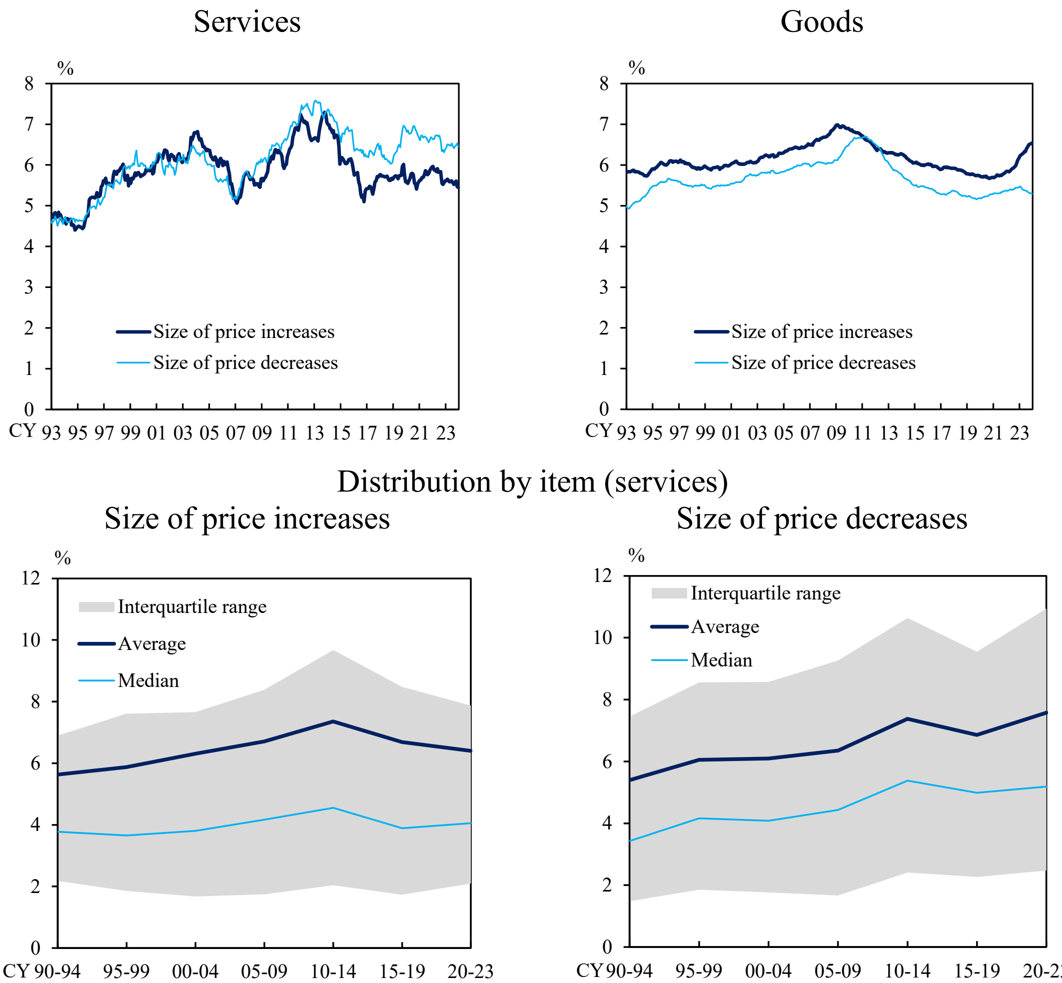
(Figure 4) Frequency of price changes



Notes: The data exclude fresh food, electricity, manufactured and piped gas, water charges, housing rent, and periods of consumption tax hikes. In the upper panels, figures are backward 36-month moving averages.
Source: Ministry of Internal Affairs and Communications.

Figure 5 separates the size of price changes into upward and downward price changes. Figure 5 (upper panels) shows the average of all items in services and goods. In contrast to the frequency, there has been no clear asymmetry between upward and downward price changes for services. Both series rose gradually, with ups and downs, from Phase I to II, rising from around 4.5 percent to 7 percent. The size of price decreases remained around this level, while the size of price increases fell during Phase III. For goods, the size of price increases remained above that of price decreases over almost the entire sample period, though the pattern of the movements were similar. Figure 5 (lower panels) shows the distributions of the size of price changes by item in services for both directions. Again, there has been no clear asymmetry between upward and downward price changes, contrasting with the developments of the frequency of price changes. It is noticeable, however, that the size of price decreases increased modestly from Phase II to III, while that of price increases declined over the same periods.

(Figure 5) Size of price changes

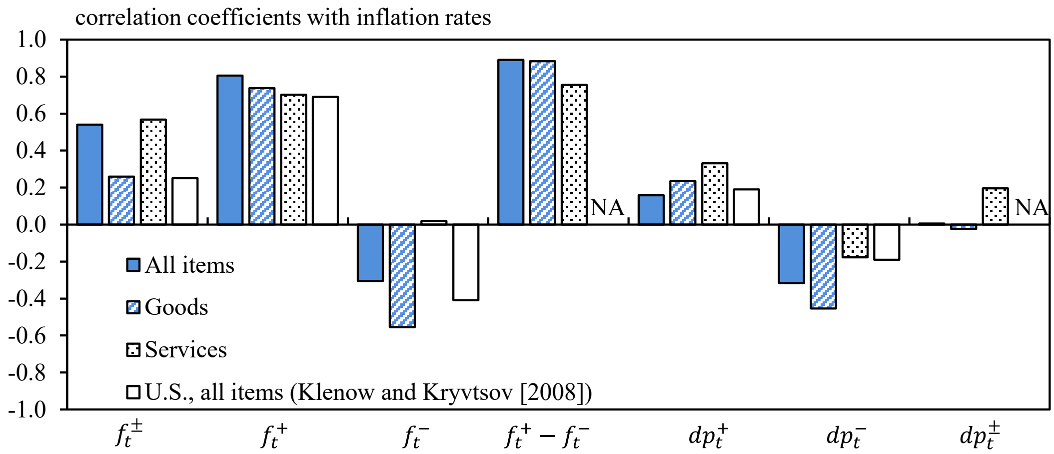


Notes: The data exclude fresh food, electricity, manufactured and piped gas, water charges, housing rent, and periods of consumption tax hikes. In the upper panels, figures are backward 36-month moving averages.
Source: Ministry of Internal Affairs and Communications.

2.4 Inflation Rate and Frequency of the Price Changes

Figure 6 shows the correlation between the inflation rate and each of the seven moments of price changes, i.e., frequency of price changes, frequency of price increases, frequency of price decreases, net frequency of price changes, size of price increases, size of price decreases, and size of price changes on an aggregate basis. There are three notable observations. First, the frequency of price changes is positively correlated with the inflation rate. A fall in the frequency of price changes is, for example, associated with a fall in the inflation rate. Second, regarding the correlation between the two variables, the positive correlation is more pronounced in services than goods. This is consistent with the observation that the frequency of price changes in the service sector fell significantly while that in the goods sector fell only modestly during the 1990s, when inflation fell. Third, in terms of the absolute value, the frequency of price increases is more responsive to a change in the inflation rate than the frequency of price decreases. This tendency is more pronounced for the services than goods. For example, the frequency of price decreases in the service sector has almost no correlation with the inflation rate while that of price increases has a significant positive correlation with the inflation rate.

(Figure 6) Correlation between moments and actual inflation rate



Notes: $f_t^{\pm}$ =frequency of price changes, $dp_t^{\pm}$ =size of price changes. Linear time trends have been removed from all series.

Next, we conduct a similar analysis using item-level data. Table 1 shows the estimation results in which the inflation rate is included as the explanatory variable and each of the frequency of price changes, price increases, and price decreases is set as the dependent variable.[9] The estimations are conducted for all items, items in the service sector, and items in the goods sector. We use the difference in the variable of interest between the current phase and the previous phase for both dependent and explanatory variables. The three points hold also in this case. First, the inflation rate affects the frequency of price changes positively at a statistically significant level regardless of the dependent variable or phase. Second, the inflation rate affects the frequency of price changes in the service sector more than price changes in the goods sector. Third, for items in the service sector, the inflation rate affects the frequency of price increases and that of price decreases in an asymmetric manner when measured in terms of the absolute value. Namely, while the inflation rate increases the frequency of price increases noticeably for both goods and service items, it decreases the frequency of price decrease only modestly in particular that in the service sector.

---

[9] While we do not show here, the three observations seen in Figure 6 hold for the correlation between yearly inflation rate and yearly changes in frequency of price changes, instead of changes of the variables over phases, at the item level.

(Table 1) Cross-sectional regression coefficients for inflation

Dependent variable	Explanatory variable	All items		Services		Goods	
		Phase I to II	II to III	I to II	II to III	I to II	II to III
Change in frequency (total)	Change in inflation rate	1.026***	1.910***	5.040***	4.758***	0.494***	1.700***
Change in frequency of price increases		4.033***	4.465***	6.621***	6.265***	3.755***	4.331***
Change in frequency of price decreases		-3.008***	-2.555***	-1.581***	-1.507***	-3.261***	-2.632***

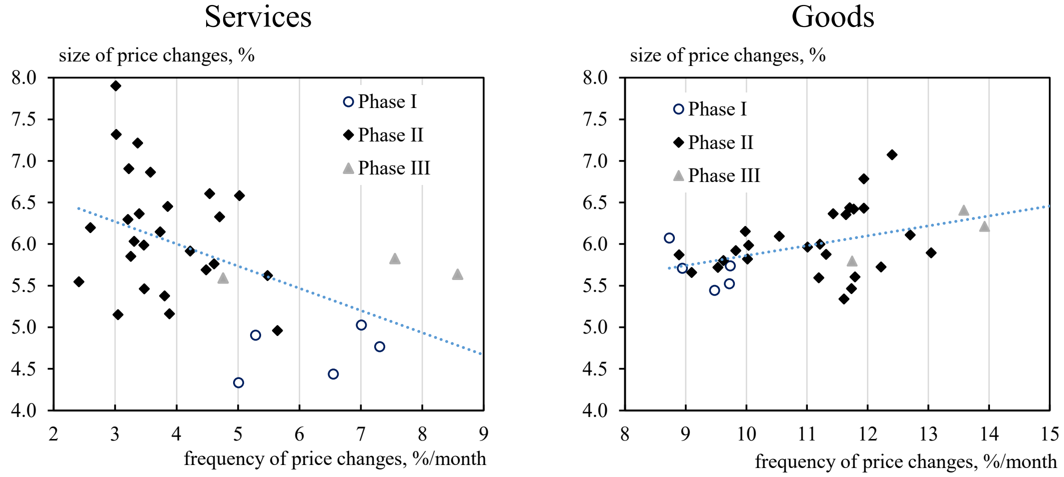
Notes: Variables are aggregate values by item and city for each phase. *** indicates statistical significance at the 1 percent level.

As discussed in a later section, a positive correlation between the inflation rate and the frequency of price changes warrant some attention. Alvarez *et al*. [2019] discuss that, both theoretically and empirically, when the inflation rate is low the frequency of price changes is insensitive to changes in the inflation rate. Along the same line, Klenow and Kryvstov [2008] point out that "movements in aggregate inflation reflect movements in the size of price changes rather than the fraction of items changing price, due to offsetting movements in the fraction of price increases and decreases." In the case of our sample, and particularly, for items in the service sector, this is not the case. The key reason for this is indeed that the fraction of price increases and decreases do not offset each other. The frequency of price increases is correlated more and that of price decreases is correlated modestly with the inflation rate so that the effects of the frequency of price increases dominate that of price decreases. This asymmetric pattern is more pronounced in the service sector.

2.5 Frequency of Price Changes and Size of Price Changes

There are weak relationships between the frequency of price changes and size of price changes. Figure 7 shows the correlation between the two variables over the three phases for the service and good sectors at the aggregate level. The correlation is negative for services and positive for goods, primarily due to the difference in how the frequency of price changes have evolved over the three phases. Table 2 shows the correlation of the two variables in terms of changes from the previous phase at the item level for all items as well as for service items and goods items separately. The coefficients are all negative, indicating that items that saw a decline in the frequency of changes tended to see a rise in the size of price changes. As discussed later, this negative correlation between the frequency and size of price changes, in particular among items in the service sector, is considered to have important information regarding the potential development of menu costs over the phases.

(Figure 7) Relationship between frequency and size of price changes



Note: Each point represents the aggregate frequency and size of price change for each year.

(Table 2) Cross-sectional regression coefficients for size of price change

Dependent variable	Explanatory variable	All items		Services		Goods	
		Phase I to II	II to III	I to II	II to III	I to II	II to III
Change in frequency (total)	Change in size of price changes	-0.029***	-0.131***	-0.047***	-0.074***	-0.031***	-0.166***

Notes: Variables are aggregate values by item and city for each phase. *** indicates statistical significance at the 1 percent level.

3 Accounting for the Data Using a State-Dependent Pricing Model

In this section, we explore if the standard model is able to account for the data dynamics from Phase I to II and from Phase II to III, in particular the frequency of price changes and the number of zero-inflation items. We use as the benchmark model the menu cost model developed by Nakamura and Steinsson [2008], calibrated to Japan's economy. We extend their model, however, so that it addresses the quasi-kinked demand structure of households (Levin, López-Salido, and Yun [2007]) along the lines of Kimball [1995].

3.1 Model

We start by describing the pricing decision of a firm z. This firm produces a differentiated product $y_t(z)$ using the following linear technology:

$$y_t(z) = A_t(z)L_t(z), \tag{3}$$

where $A_t(z)$ denotes the productivity of the firm's labor force in period t, and $L_t(z)$ denotes the quantity of labor hired by the firm z for production purposes in period t.

As for the demand structure, we depart from the original setting of Nakamura and Steinsson [2008] and incorporate a quasi-kinked demand system following Kimball [1995]. More precisely, we assume that the demand for the product of firm z. $c_t(z)$ is expressed as follows.

$$c_t(z) = \frac{C}{1+\eta}\left[\left(\frac{p_t(z)}{P_t}\right)^{-\epsilon(1+\eta)} + \eta\right], \tag{4}$$

where $p_t(z)$ denotes the nominal price the firm charges in period t, P_t denotes the aggregate price level in period t, $\epsilon > 1$ represents the elasticity of substitution between individual differentiated products, and C is a constant that determines the size of the market for the firm's product.[10]

The parameter η plays the key role in determining the demand for the product. When $\eta = 0$, the demand curve exhibits constant elasticity, as in the Dixit-Stiglitz formulation. When $\eta < 0$, the firm faces a quasi-kinked demand curve so that a drop in its relative price results in only a small increase in demand, while a rise in its relative price generates a large drop in demand. In other words, the elasticity of demand for the product, denoted $\theta(c_t(z))$, varies inversely with relative demand $c_t(z)$; $\theta(c_t(z)) = \epsilon(1+\eta-\eta c_t(z)^{-1})$. To capture the price rigidity observed in the data, we assume that the firm must hire an extra K^+ units of labor in order to raise its price, and K^- units of labor to lower its price. K^+ and K^- can be interpreted as the menu costs the firm incurs when changing prices. While existing studies typically assume K^+ equals K^-, in this paper we relax this assumption and allow menu costs to differ between price increases and decreases.

For simplicity, we assume that the real wage rate in the economy is given by the desired markup of individual firms, given by

$$\frac{W_t}{P_t} = \frac{\epsilon - 1}{\epsilon}, \tag{5}$$

where W_t denotes the nominal wage in the economy at time t.[11] Using equations (3), (4), and (5) and the fact that markets clear ($c_t(z) = y_t(z)$), we can write real profits $\Pi_t(z)$ as

[10] In a general equilibrium setting, the demand function in equation (4) could also depend on the Lagrange multiplier of the final good producer, as in Levin, López-Salido, and Yun [2007]. Since our model is a partial equilibrium model, we shut off this general equilibrium effect and normalize the Lagrange multiplier to unity.

[11] The inverse of equation (5) represents the theoretical markup, which is the reciprocal of the labor share. The aggregate labor share in Japan has been more or less flat in the long run compared to other countries, such as the United States. Therefore we do not consider short run fluctuations in the aggregate markup.

$$\Pi_t(z) = \frac{C}{1+\eta}\left[\left(\frac{p_t(z)}{P_t}\right)^{-\epsilon(1+\eta)} + \eta\right]\left(\frac{p_t(z)}{P_t} - \frac{\epsilon-1}{\epsilon}\frac{1}{A_t(z)}\right) - \frac{\epsilon-1}{\epsilon}\left(K^+ I_t^+(z) + K^- I_t^-(z)\right), \tag{6}$$

where $I_t^+(z)$ $(I_t^-(z))$ is an indicator function that takes a value of unity when the firm chooses to increase (decrease) price at time *t* and takes a value of zero otherwise.

We assume that the logarithm of productivity $A_t(z)$ of the firm's labor force follows an AR(1) process:

$$\log A_t(z) = \rho \log A_{t-1}(z) + \varepsilon_t(z), \tag{7}$$

where ρ is the auto-regressive parameter and $\varepsilon_t(z) \sim N(0, \sigma_\varepsilon^2)$ is an idiosyncratic productivity shock.

We assume that the logarithm of the aggregate price level P_t fluctuates around a trend,

$$\log P_t = \mu + \log P_{t-1} + \delta_t, \tag{8}$$

where μ is the trend inflation rate and $\delta_t \sim N(0, \sigma_\delta^2)$ is a shock to trend inflation.

The firm maximizes profits discounted at a constant rate β. The value function of the firm is given by

$$V(p_{t-1}(z)/P_t, A_t(z)) = \max_{p_t(z)}[\Pi_t(z) + \beta E_t V(p_t(z)/P_{t+1}, A_{t+1}(z))], \tag{9}$$

where E_t denotes the expectation operator conditional on information known at time *t*. We solve the firm's problem by value function iteration on a grid. We approximate the process for $A_t(z)$ and P_t using the method proposed by Tauchen [1986].

3.2 Calibration

We set the values of most of the parameters following Nakamura and Steinsson [2008] in terms of the values themselves or the methodology employed. For β and ϵ, we use their values of $0.96^{1/12}$ and 4, respectively. For μ and σ_δ, we set the values based on the CPI inflation rate in the first half of the 1990s in Japan. We calibrate ρ to 0.66. The curvature parameter η is set to 0 in the baseline model, which means that the price elasticity of demand is constant. We choose the values of parameters σ_ε^2, K^+, and K^- to match the estimates of the frequency of regular price changes, the fraction of regular price changes that are price increases, and the size of regular price changes during this period.

For comparison, we extract the values of these parameters not only for service prices but also for goods prices and prices in the U.S. Note that when we use the data of service prices for Japan, we exclude rent as in the U.S. data.

Table 3 shows the results. First, there is a noticeable asymmetry regarding menu costs for upward and downward price changes, K^+ and K^-, in services. For downward price changes, 2.4 percent of unit labor is needed while 1.1 percent is needed for upward price changes. This result is consistent with the observation that downward nominal rigidity was present in Japan until the late 1990s.[12] Second, the menu cost asymmetry is reversed for services versus goods prices in Japan. That is, the menu costs of upward price changes are larger than those of downward price changes for Japanese goods. Third, menu costs tend to be larger in Japan than in the U.S. For example, there are qualitatively similar asymmetries in U.S. service prices to those in Japan, but even the menu cost of a downward price change in the U.S. is smaller than the menu cost of an upward price change in Japan.

(Table 3) Calibrated parameters using the data of Phase I (1990-94)

Parameters		Japan		United States	
		Services	Goods	Services	Goods
K^+	Menu cost to raise price	1.1%	1.7%	0.3%	0.4%
K^-	Menu cost to lower price	2.4%	0.7%	0.9%	0.7%
σ_ε	Variance of idiosyncratic productivity shock	2.9%	2.8%	2.5%	2.5%

Notes: We used the U.S. store-level moments of price changes from Nakamura and Steinsson [2008, 2010] after adjusting them to be comparable with the Japanese city-level moments, using the relationship between the Japanese store-level and city-level moments. Sample period for the United States is from 1998 to 2005.

3.3 Simulations with Actual Inflation Rates

Using the model, we perform a set of simulations to examine how much of the emergence of the norm can be explained by changes in the actual inflation rate. We feed through the actual inflation rate from the 1990s to 2020s into the menu cost model described above. To ensure robustness, we use two types of models: the first type of model takes as inputs the time path of the aggregate inflation rate and yields changes in the frequency and size of the aggregate price changes. We refer this as the aggregate model. The second type of model takes as inputs the time path of each of the sectoral inflation rates and yields changes in the frequency and size of price changes in the sectoral price changes. We refer to these as the item-level models. Note that there are around 100 item-

[12] Kuroda and Yamamoto [2003], for example, study Japan's nominal wage data from 1993 to 1998 and report that the nominal wage change distributions are statistically skewed to the right with large spikes near zero. They stress that the observation is consistent with the presence of downward nominal wage rigidity.

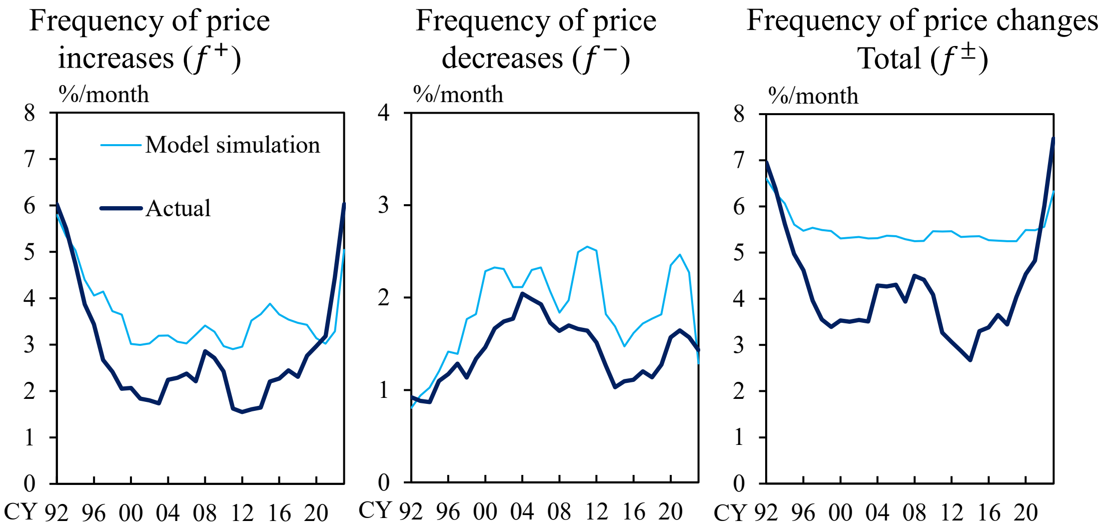
level models, each of which is calibrated to the respective actual frequency and size of price changes in the early 1990s.

For each exercise, following the procedure used by Nakamura and Steinsson [2008], we provide the model with the value of each year's actual inflation rate for a specific sector or item over the years 1990 to 2023, simulate the model 100,000 times, and calculate the average frequency and size of price changes generated from the model. We provide the aggregate inflation rate of the service sector for the aggregate model and actual item-level inflation rate for each of the item-level models.

Figure 8 shows the time path of the frequency of price changes generated from the aggregate model. The model with the actual inflation rate tracks the time path of the actual frequency of price changes well qualitatively. In particular, the frequency of price changes is high during Phases I and III, when relatively high inflation rates prevailed, compared with that during Phase II, when lower inflation rates prevailed. The model also tracks the asymmetric response of the frequency of price increases and decreases. As in the data, the model predicts a fall in the frequency of price increases from Phase I to II is larger than a rise in the frequency of price decreases during the same period in terms of absolute changes.

Quantitatively, however, the model does not fully agree with the data regarding the norm. As shown in the right panel of the figure, the model-generated frequency of price changes falls from 7 percent to 6 percent from Phase I to II, while the actual frequency of price changes falls to 3.5 percent. This is because, as shown in the left and middle panels, for the transition from Phase I to II, the model predicts a smaller decline in the frequency of price increases and a larger rise in the frequency of price decreases compared with the data.

(Figure 8) Effects of trend inflation rate



Note: Figures are backward 3-year moving averages.

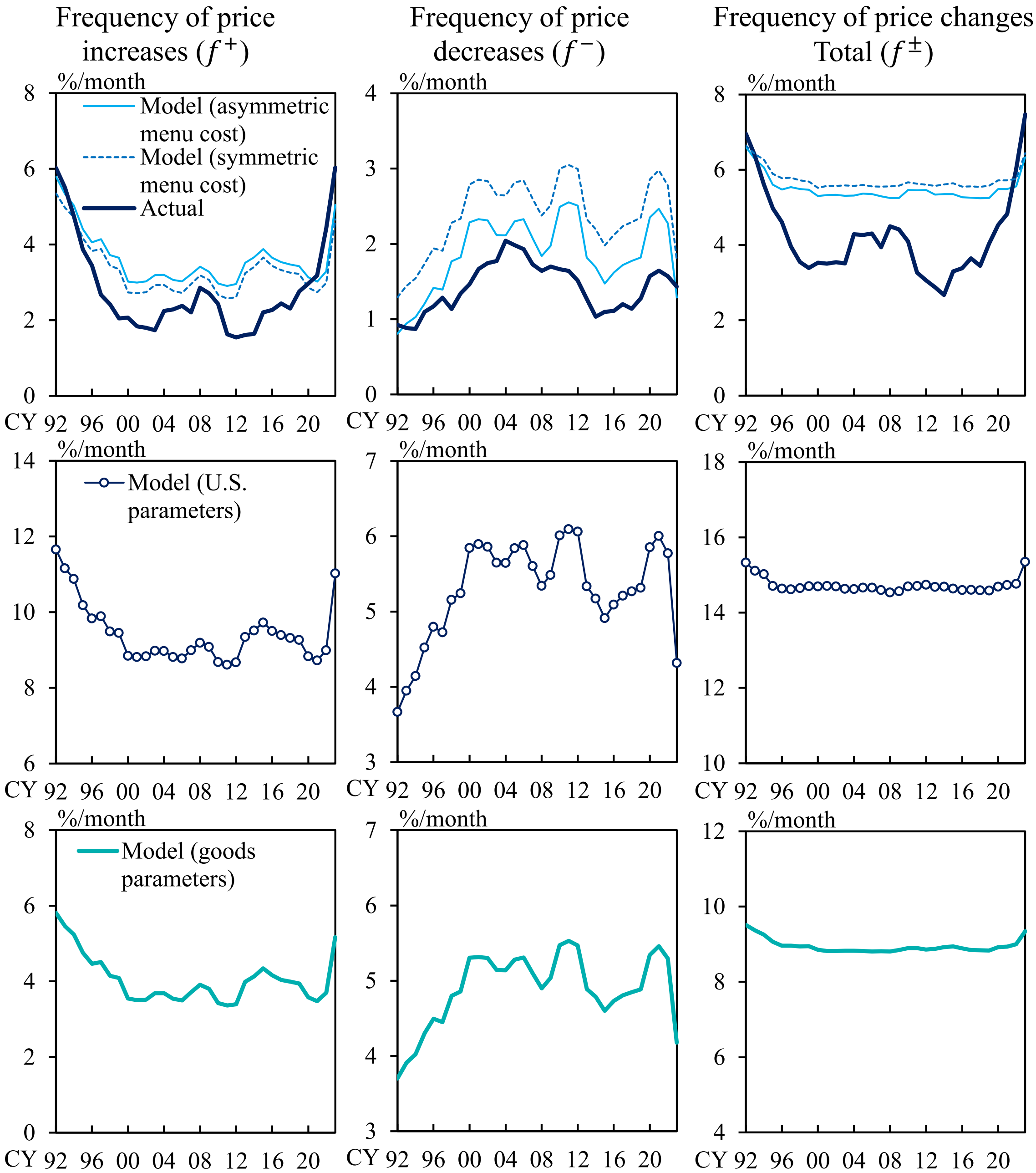
Parameter values of the model, in particular the sizes of menu costs, matter greatly to the simulation result. Figures 9 and 10 show the simulation results under several different settings of menu costs. The upper panels in Figure 9 show the series of frequency of price changes generated from the model with menu costs that are symmetric for both upward and downward price changes.[13] As the upper-right panel shows, this alternative model also accounts for the emergence of the norm qualitatively, in the sense that the frequency of price changes declines from Phase I to II, reflecting an asymmetric change in frequency of price increases and decreases. The gap between the data and model, however, becomes larger compared with that shown in Figure 8. The middle and lower panels in Figure 9 show the series generated from the model with menu costs that are calibrated to the U.S. values and goods values, respectively.[14] For the case of U.S. menu costs, the frequency of price changes is already high in Phase I and the decline in the frequency of price changes from Phase I to II is muted compared with the baseline. In other words, even if the same time path of the inflation rate as Japan had materialized in an economy with the menu costs of the U.S., the frequency of price changes would have been around 15% and the zero-inflation norm would not have occurred. As implied from the size of menu costs shown in Table 3, in this case firms are active in changing their prices, making the level of frequency of price changes higher and changes in the frequency of price changes smaller. The latter holds because, as shown in Figure 8, changes in the frequency of price increases and decreases cancel out. As a result, the zero-inflation norm is less likely to happen. For the case of goods menu costs, because the menu cost for price decreases is relatively small, the frequency of price changes is already high in Phase I and also throughout the subsequent phases as compared with the case of the baseline. As shown in Figure 10, because the menu costs of price increases are larger for goods than services, a decline in frequency of price increases from Phase I to II becomes modest, leading to a muted decline in the frequency of price changes from Phase I to II.

---

[13] For this exercise, we calibrate the parameters to the data of the early 1990s, assuming the menu costs are symmetric for price increases and decreases. Model features and the time path of the actual inflation rate used as inputs are the same as those used for the simulation above.

[14] For these exercises, we calibrate the model parameters to values shown for the U.S. and for goods in Japan in Table 3, respectively. Again, the model settings and the time path of the actual inflation used as input as the same as those used for the simulation above.

(Figure 9) Effects of trend inflation



Note: Figures are backward 3-year moving averages. "Model (U.S. parameters)" and "Model (goods parameters)" are the results of counterfactual simulations by models calibrated using U.S. services data and Japanese goods data, respectively.

(Figure 10) Change in the frequency of price changes

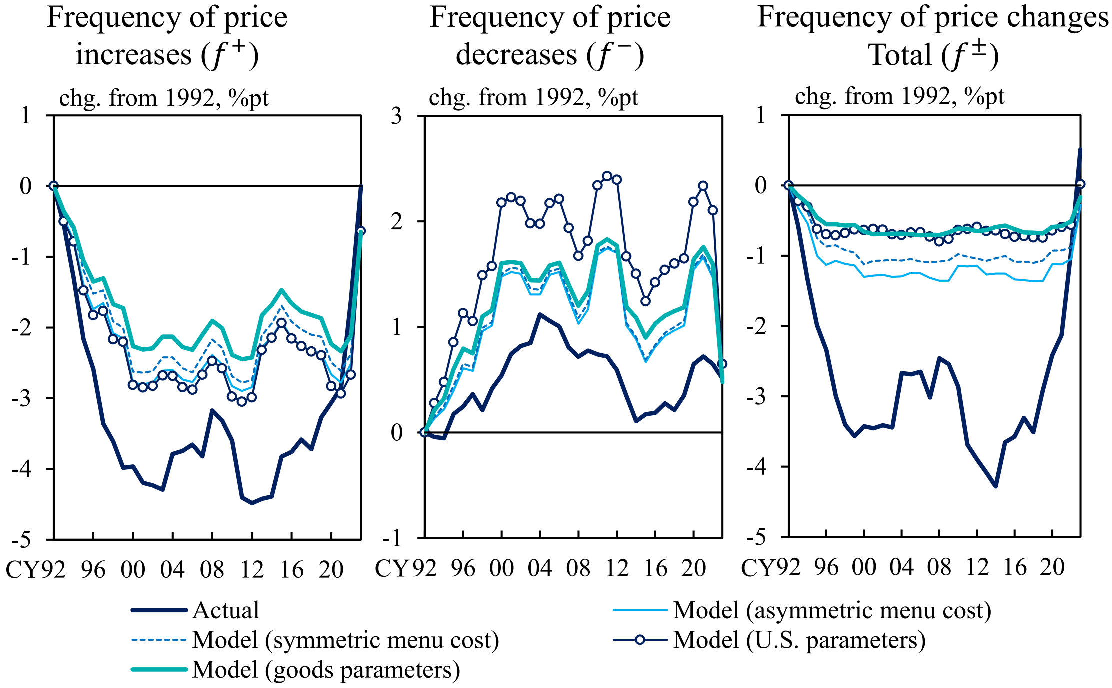
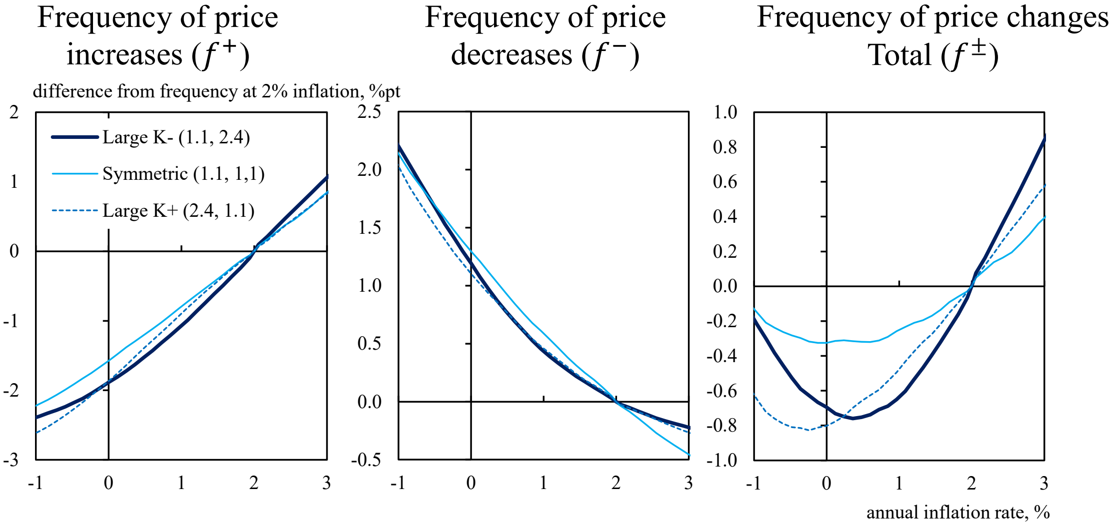


Figure 11 shows a relationship between the frequency of price changes and trend inflation rate that is generated from our menu cost model with various different assumptions of the menu cost. Two observations are notable. First, it is notable that when menu costs are large, frequency of price increases falls greater and frequency of price decreases rises more modestly in response to a decline in the inflation rate from some positive values to a value around zero. Notice that with a positive trend inflation rate, firms' relative price gradually fall as far as they do not change their prices. Firms change their prices only when the price gap, the deviation of the current price from the desired price, becomes large enough so that the benefits of changing the prices exceed the menu costs. The fall in the trend inflation rate makes such price changes less frequent and the effect is more pronounced when the menu costs are large. Second, some forward-looking behavior matters to firms' price changes. For example, with large menu costs for downward price changes, firms become more reluctant to raise price because it would be costly for the firms to reduce prices once they set higher prices. Consequently, the frequency of price increases falls greater in response to a decline in the inflation rate from a positive value when menu costs for downward price changes are larger. These observations are consistent with the findings shown in Figure 10 that changes in the frequency of price changes become muted when the menu costs are calibrated to the U.S. price dynamics or the price dynamics of the goods sector in Japan.

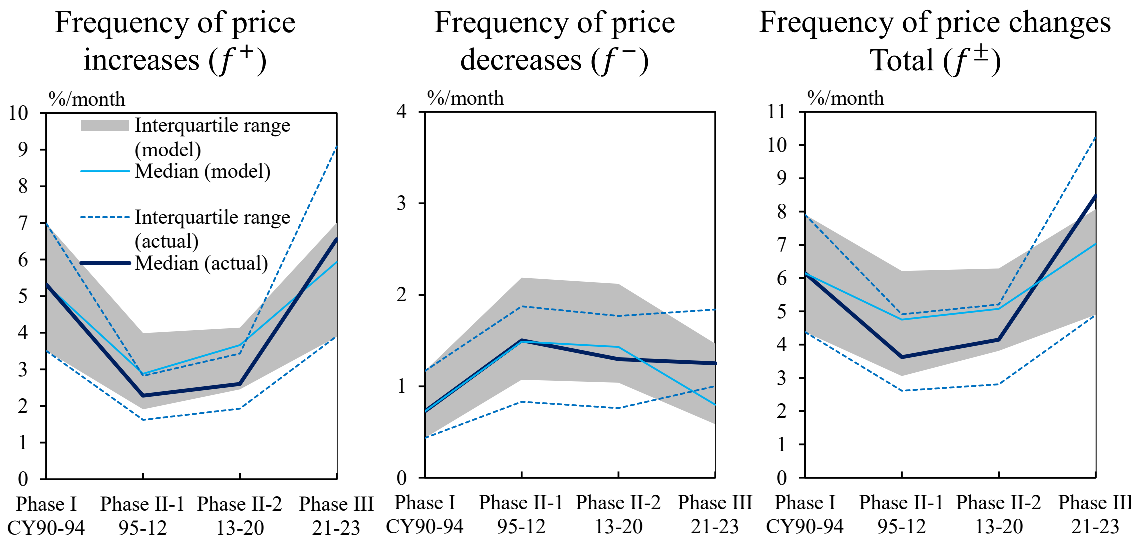
(Figure 11) Size of upper and lower menu costs and frequency of price changes



Note: Numbers in parentheses indicate the upper and lower menu costs (K^+, K^-) (in percentage).

Figure 12 shows the time path of the frequency of price changes generated from the item-level models. Because there are 100 items in the service sector, there are 100 corresponding model-generated frequency series. The figure shows the distribution across items of the model-generated frequencies and the data frequency, represented by the interquartile range and median of the series. Similar observations hold to the results obtained with the aggregate model. Namely, the model agrees with the data qualitatively but not fully quantitatively. For example, the median of the model-generated frequencies of price changes falls by 1 percent from Phase I to II while that of the data falls by more than 2 percent. It can also be seen that for the transition from Phase I to II, the model predicts a smaller decline in the frequency of price increases and a larger increase in the frequency of price decreases compared with the data.

(Figure 12) Effects of trend inflation

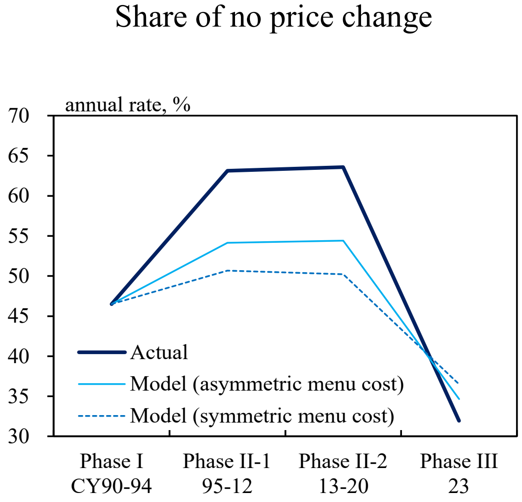


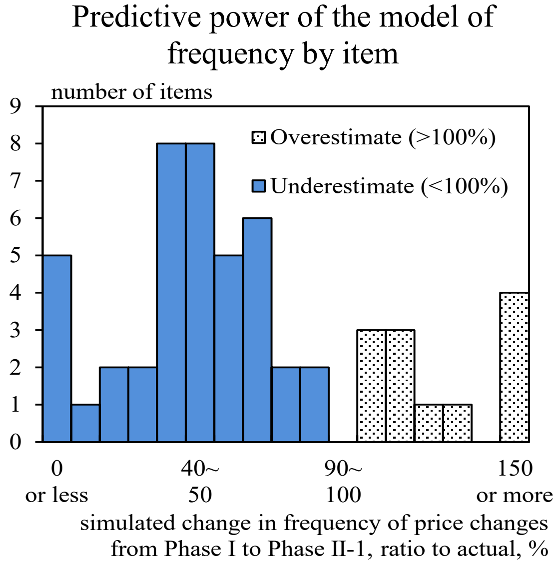
Notes: The data are limited to items for which data are available in Phase I. Constants are added so that the model estimates match the actual values in Phase I.

Figure 13 summarizes the simulation results based on the aggregate model on the left and those based on the item-level models on the right. The aggregate model correctly predicts the data movement qualitatively: a rise in the share of zero-inflation items from Phase I to II and its decline from Phase II to III. Quantitatively, however, for example, only about 40 to 50 percent of the rise in the share from Phase I to II is explained by the decline in the actual inflation rate. The right panel computes the proportion of declines in model-generated frequencies from Phase I to II compared with the actual decline in frequency for 100 service items. The item-level models underestimate the change in frequency from Phase I to II for more than half of the items.[15]

[15] The fact that the frequency of price changes has decreased significantly as the inflation rate has declined is indeed in contrast with the findings of Alvarez *et al.* [2019], which shows that under low inflation, the frequency of price changes does not change with inflation. This can be partly explained by the relatively large and highly asymmetric menu costs in the Japanese services sector, according to our model analysis above. If the menu costs were at U.S. levels or symmetric, this would be less likely to occur.

(Figure 13) Effects of trend inflation



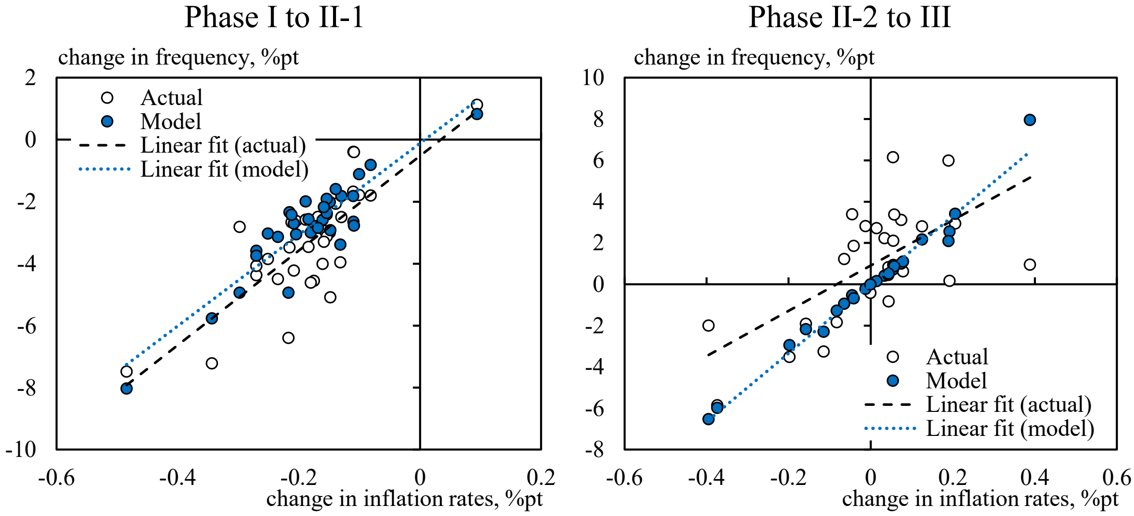


Note: Share of no price change (annual rate) = (1 – frequency of price change)^{12}.

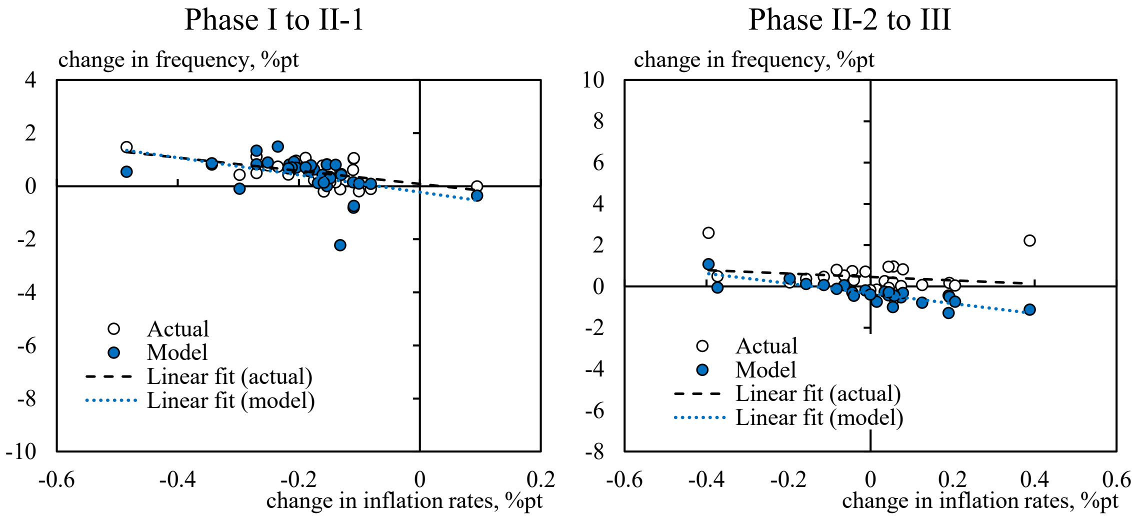
It is also notable that the item-level models are able to replicate a positive correlation between the frequency of price changes and the inflation rate at the item level seen in the data. Figure 14 shows the correlation between the two variables, in terms of the difference from the previous phase, generated from the model for the service sector and goods sector. For comparison, we plot the correlation of the two variables in the actual data as well. Changes in the frequency of price changes are positively correlated with changes in the inflation rate over the different phases and the positive correlation between the two variables is more pronounced in the service sector than good sector. It is also notable, however, for changes in frequency of price changes, that the slope for the actual data is steeper and the intercept for the actual data is smaller than the model estimates, indicating there are potentially other factors operating.

(Figure 14) Change in inflation and simulated frequency of price changes by item

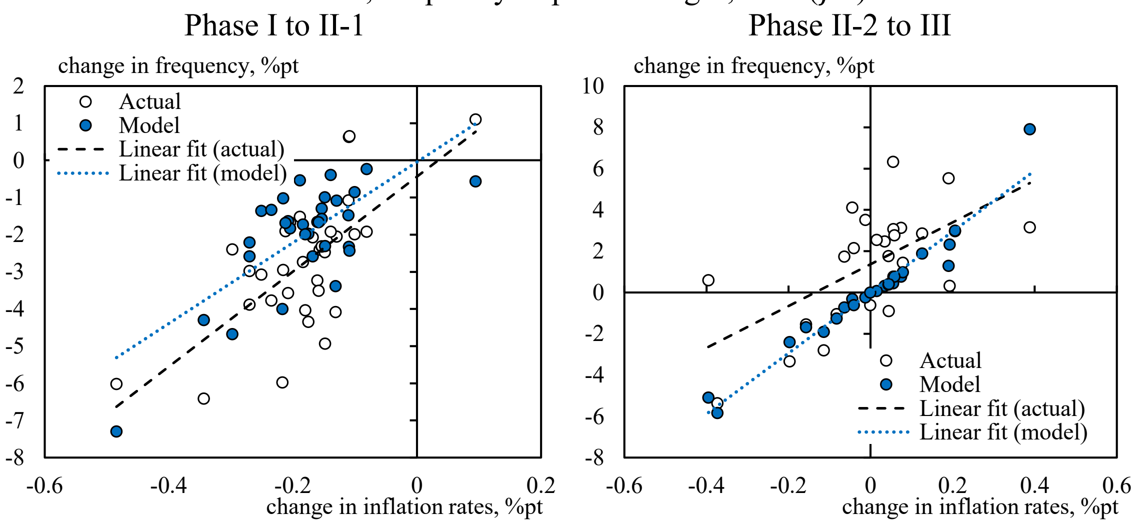
Services, frequency of price increases (f^+)



Services, frequency of price decreases (f^-)



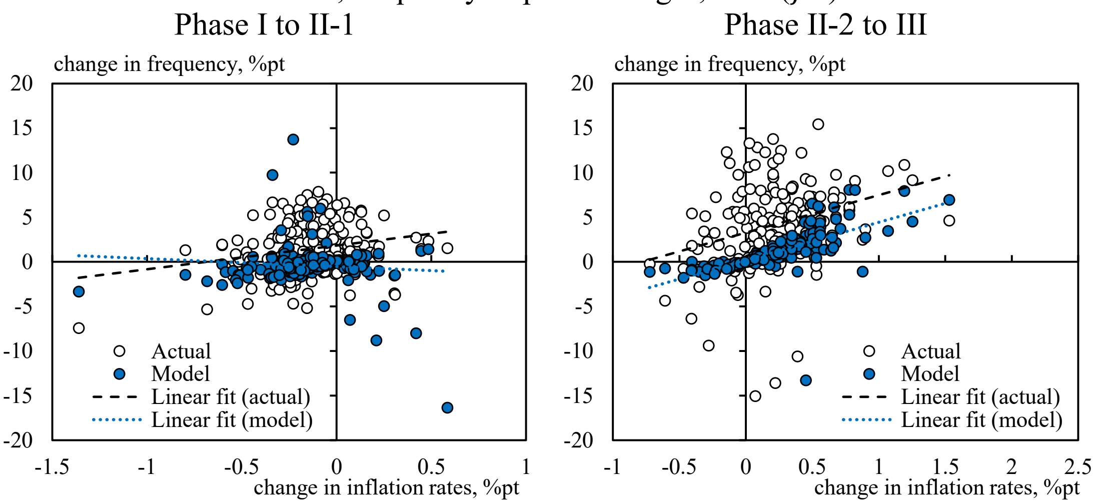
Services, frequency of price changes, total ($f^\pm$)



Note: Actual points are plotted only for items for which simulation results are available.

(Figure 14) Change in inflation and simulated frequency of price changes by item (continued)

Goods, frequency of price changes, total ($f^{\pm}$)



Note: Actual points are plotted only for items for which simulation results are available.

4 Role of Changes in Model Parameters

Our next step is to fill the remaining gap between what the model with the actual inflation rate predicts and the data. We consider the possibility that some model parameters might have changed over the phases and explore how the key model parameters should have evolved over time to be consistent with the actual developments of the frequency and size of price changes, using various types of menu cost models.

Figure 15 shows several candidate explanations for why Japanese firms did not pass on their costs to prices during the period of low inflation, based on the survey results reported in Bank of Japan [2024].[16] Indeed, there are various reasons. About 70% of responding firms indicate that concerns about price competition prevented them from passing on the costs to prices. About 30% of respondent firms indicate that consumers' attitudes, corporate image, or costs associated with arrangements are the reasons. With reference to the survey results, we choose two model parameters, allow them to change over time, and quantify changes in values of these parameters.

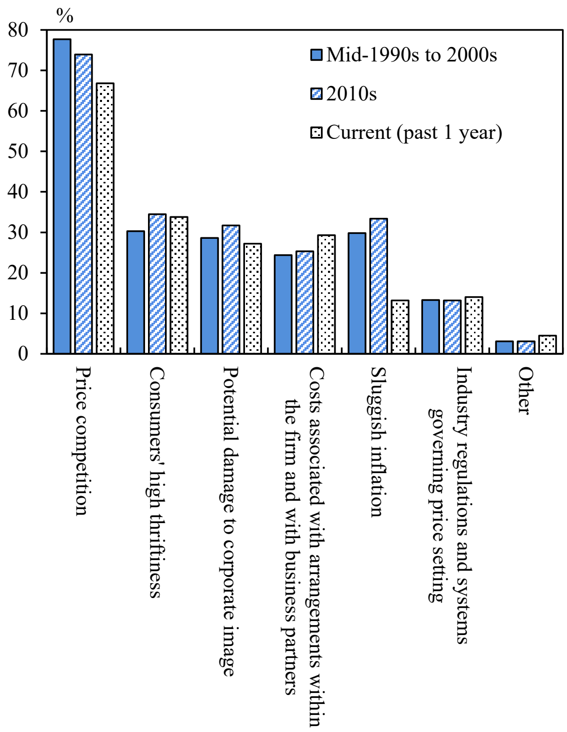
The first parameter is the parameter that governs the curvature of demand elasticity η. Changes in this parameter are considered to represent a change in price competitiveness. Indeed, the possibility of a change in the curvature of demand elasticity has already been

[16] Bank of Japan [2024] documents the results of the survey conducted by the Bank of Japan. The survey was conducted with the aim of deepening the Bank's understanding of the features of corporate behavior since the mid-1990s and the impact this behavior has had on Japan's economic developments and the formation mechanism of wages and prices, as part of the Bank's Review of Monetary Policy from a Broad Perspective. The survey covers around 2,500 nonfinancial corporations nationwide of varying industries and sizes in Japan.

discussed in existing studies, such as Watanabe [2023] and Watanabe and Watanabe [2018]. The second parameter is that which governs the size of menu costs K^+. Obviously changes in this parameter represent changes in the cost of adjusting prices in general. As discussed in Zbaracki *et al.* [2004], this menu cost is considered as reflecting various types of non-physical costs, including costs associated with arrangements with the customers.

In addition to these two parameters, in some exercises, we allow the variance of idiosyncratic productivity σ_ε^2 to change during the simulation period. Indeed, as discussed in Alvarez *et al.* [2019], a theoretical reason why the frequency of price changes is considered to become nonresponsive to changes in the inflation rate in low inflation rate environment is because idiosyncratic shocks become relatively more important than the inflation rate. Obviously, other things being equal, a decline in the variance of idiosyncratic shock should make firms inactive in price changes and more responsive to a change in the inflation rate.

(Figure 15) Reasons for the difficulties in passing on higher costs to prices

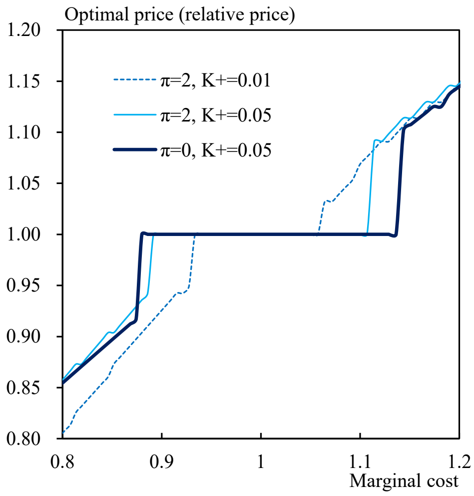


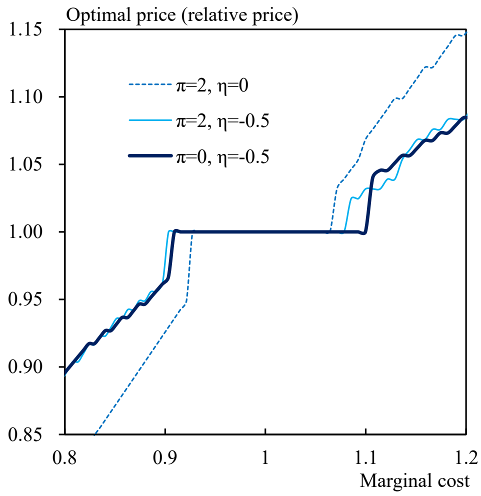
Source: Bank of Japan [2024]

Figure 16 shows the policy function of how firms change their prices in response to changes in marginal costs, derived from our main model, for various sizes of menu costs on the left and various sizes of curvature on the right. Note that the horizontal axis represents the marginal cost in period 1, where its long-run average is normalized to 1.

(Figure 16) Inaction region to change in marginal costs

Menu cost parameter (K^+) Curvature parameter (η)





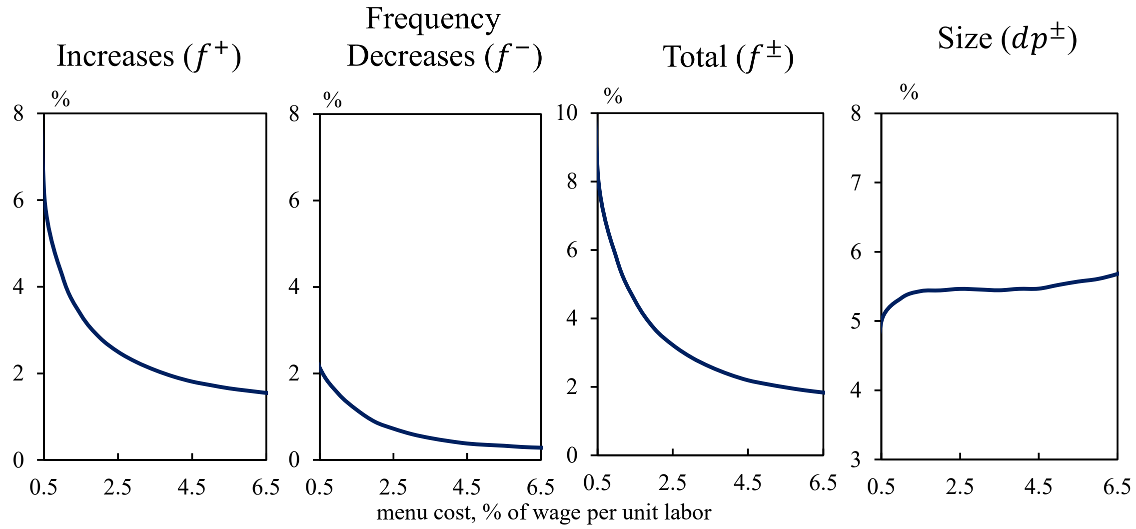
Larger menu costs widen the inaction region of price changes, as can be seen by a longer plateau, and, at the same time, increase the size of price changes, as can be seen in the magnitude of price changes at points just outside the inaction region. Because firms change their prices only when changes in marginal costs are sufficiently large, when the gap between the current price and profit-maximizing price is large, the size of price changes tends to be large. The implications of higher curvature in the demand curve (i.e., a smaller value of η) depend on the size of the trend inflation rate. On the one hand, a smaller value of η widens the inaction region as firms know that demand for their goods would decline more if they changed their prices. On the other hand, when the trend inflation rate is high, a firm's relative price changes automatically even without changing the nominal price, which, in turn, implies that the firm faces an added incentive to change its price so that the relative price remains in accordance with the prices of other firms.

Figures 17, 18, and 19 show the effects on the extensive and intensive margins of price changes, of the menu cost parameter, the curvature of the demand curve, and the variance of idiosyncratic productivity, respectively. As the menu cost parameter K^+ becomes larger, the frequency of price changes falls for both upward and downward price changes. The changes of the size of the price changes increase with menu costs, because firms change their prices only when changes in profits by doing so exceed the large menu costs.

For the curvature parameter of the demand curve η, higher curvature (i.e., a smaller value of η) reduces the frequency and size of price changes when the trend inflation is zero due to enhanced strategic complementarity. As the trend inflation rate becomes more positive, however, firms change their prices more quickly so that their relative prices are aligned with the prices of other firms because a high trend inflation rate makes their relative prices smaller even without nominal price changes.

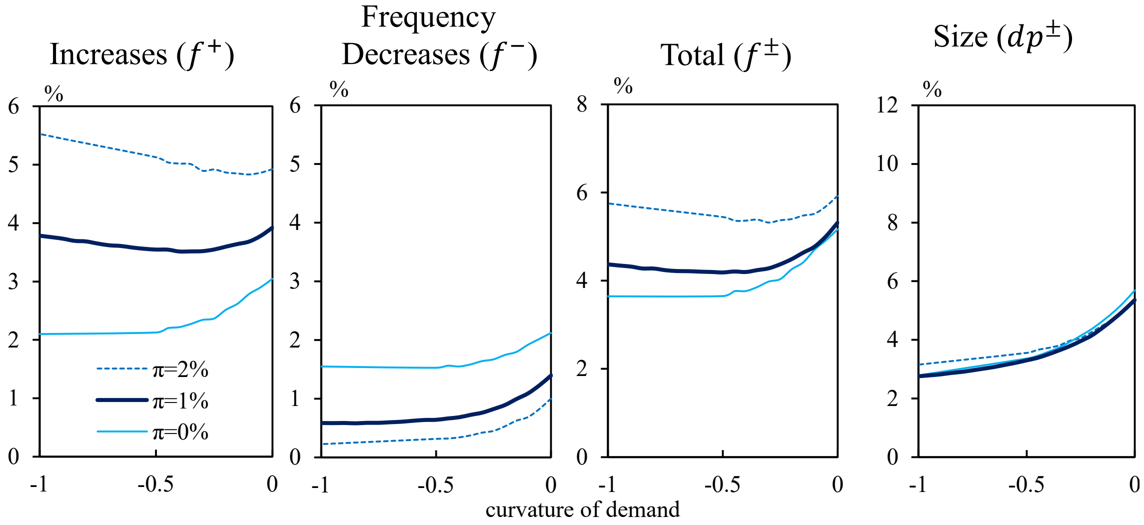
For the variance of idiosyncratic productivity σ_ε^2, higher variance raises the frequency and size of price changes due to increased variations in marginal costs facing firms. All else being equal, the price gap, i.e., the difference between the actual price and the desired price, tends to widen more, making firms more active in changing their prices. It is notable that the effect of changes in the variance on the frequency and size of price changes materialize somewhat nonlinearly. Neither frequency nor size responds to changes in the variance for values below two and both become responsive to changes when the values exceed approximately two.

(Figure 17) The role of menu costs (K^+)



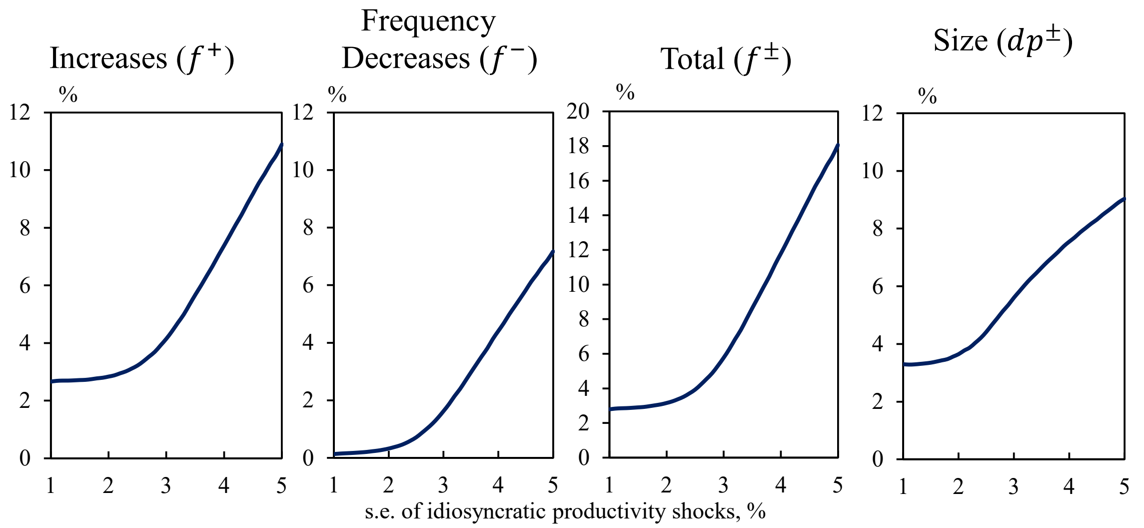
Note: The annual inflation rate is set to 1%.

(Figure 18) The role of elasticity (η)



Note: π denotes annual inflation rate.

(Figure 19) The role of variance of idiosyncratic productivity shock (σ_ε)



Note: The annual inflation rate is set to 1%.

4.1 Accounting for the Remaining Gaps

For the simulations, we employ five different approaches using both the aggregate model and item-level models as described in Table 4 below for ensuring robustness.

(Table 4) Five approaches to deriving the set of parameter values

Approach	Model	Parameters			Target moments
		Menu cost K^{+}	Curvature η	Variance of idiosyncratic shocks σ_{ε}^{2}	
Baseline	Aggregate	Latent	Latent	Observable	f+, dp
Alternative 1	Aggregate	Latent	0	Observable	f+
Alternative 2	Aggregate	Constant	Latent	Observable	f
Alternative 3	Aggregate	Latent	Latent	Latent	f+, f-, dp
Alternative 4	Item-level	Latent	Latent	Latent	f+, f-, dp

Notes: "Latent" indicates that the parameter is the target parameter of the method of simulated moments and was calibrated at each time period. f=frequency of price changes, f+=frequency of price increases, f-=frequency of price decreases, and dp=size of price changes.

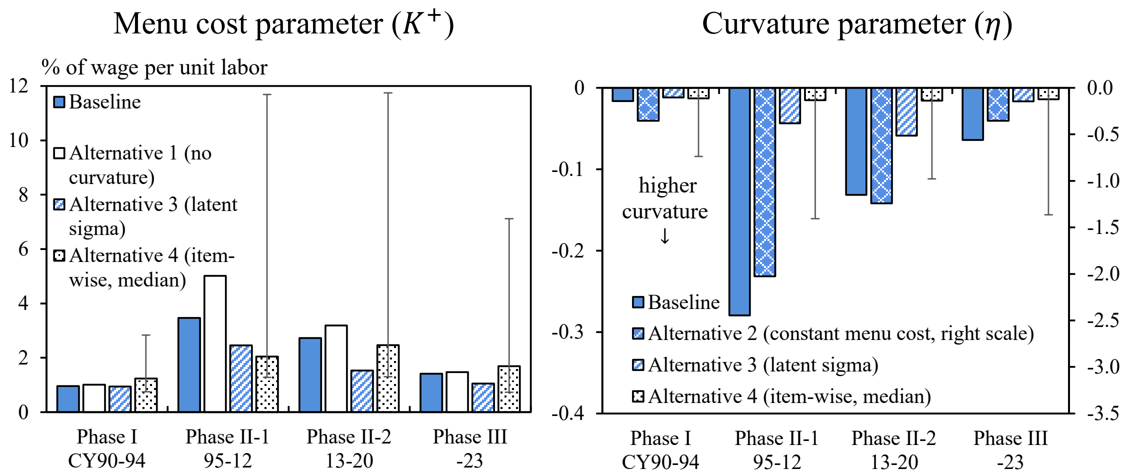
These approaches differ in terms of which type of the two models is used for the simulation (i.e., aggregate model vs item-level models), which of the parameters are allowed to vary, observables used as inputs, and the target moments. Note that because our interest is in exploring the roles of the three parameters, but particularly the parameters K^{+} and η, in explaining the remaining portion of the data that is not accounted for by the inflation rate, for all of the five approaches, we feed through the actual inflation rate into the model and attribute the unexplained portion of the target moments to changes in the parameters.[17] In the baseline approach, for example, we first feed through the actual aggregate inflation rate and the proxy of the variance of idiosyncratic productivity shocks constructed by the methodology described in Appendix C. We then estimate the time path of the two parameter values, menu cost (K^{+}) and curvature (η), so that the model-generated frequency of price increases and the size of price changes agree exactly with the data counterparts.

Figure 20 shows the estimated values of the two parameters based on various approaches for Phases I, II, and III. Note that we show the median and dispersion of the parameters estimated by alternative approach 4 because it employs 100 item-level models. Indeed, these approaches more or less agree on the development of the two key parameters. That is, all of the approaches agree that menu costs are larger and the curvature is higher (curvature parameter being more negative) during Phase II than Phases I and III. In other words, firms became more inactive and more cautious in Phase II. These changes in the

[17] Though the variance of idiosyncratic shocks σ_{ε}^{2} is not observable, similar to the other two parameters K^{+} and η, it differs from these two parameters in the sense that some proxy variables can be constructed. We therefore conduct an approach that treats the variance as observable and an approach that treats the variance as the latent variable. For example, in the baseline approach, we treat the variance as observable. See Appendix C for the construction methodology of the variance that is used as an observable input in some of the approaches.

parameter values are consistent with views of firms shown in Figure 15 and those of existing studies about the zero-inflation norm, at least qualitatively. A higher menu cost during Phase II and III is consistent with the term "social norm" in the sense that it implies that firms find it more costly to deviate from a zero inflation rate than before. A higher kinkedness of the demand curve is also consistent with existing research that emphasizes the role of strategic complementarity stemming from a higher curvature in the demand curve in explaining the zero-inflation norm (Watanabe and Watanabe [2018], Aoki, Ichiue, and Okuda [2019]).

(Figure 20) Changes in parameters over time



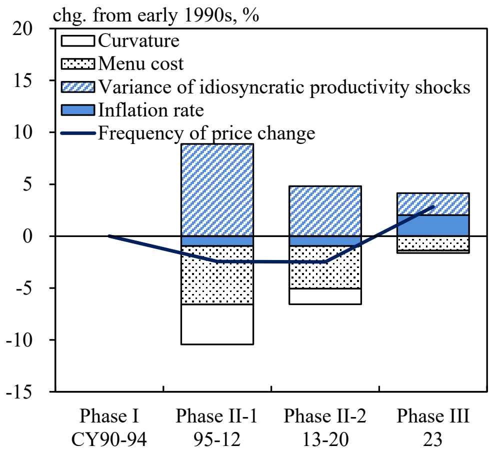
Note: The range indicates the 25th to the 75th percentile for the menu cost parameter and the 10th to the 90th percentile for the curvature parameter. The sample period for Phase III is 2023 for the baseline and alternatives 1 and 2, and 2021-2023 for alternatives 3 and 4.

Figure 21 shows the time path of a breakdown of the frequency and size of price changes based on the baseline approach and on alternative approach 3. As shown in Table 4, the key methodological difference is that the variance of idiosyncratic shocks σ_ε^2 is treated as a latent variable in approach 3. Three observations are notable. First, changes in the menu costs and those in the curvature of the demand curve contributed negatively and importantly to a fall in the frequency of price changes from Phase I to II. Their negative contribution to the frequency of price changes become muted from Phase II to III, which implies that these changes are important but not permanent. Second, regarding the contribution to changes in the frequency of price changes, quantitatively, the effect of a rise in menu costs has been larger than that of an increase in the curvature. Lastly, both approaches agree that the variance of idiosyncratic shocks σ_ε^2 has increased over time, boosting both the frequency and size of price changes during these periods. This implies that all else equal the zero-inflation norm would have become larger if changes in the variance had been absent.

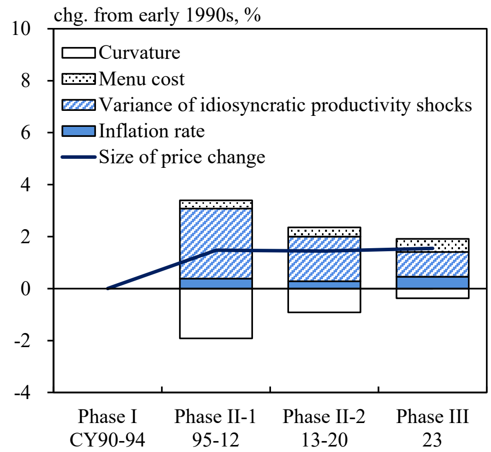
(Figure 21) Parameter decomposition of frequency and size of price changes

Baseline

Frequency of price changes ($f^{\pm}$)

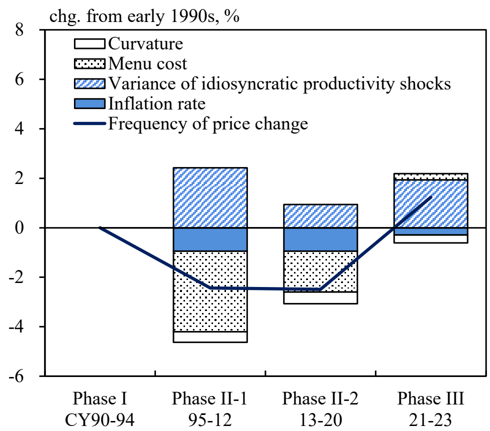


Size of price changes ($dp^{\pm}$)

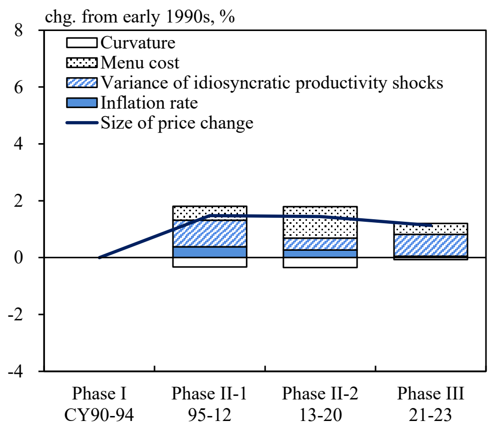


Alternative 3

Frequency of price changes ($f^{\pm}$)



Size of price changes ($dp^{\pm}$)



Note: The contribution of each parameter is the difference in moments when the parameter is changed from its calibrated parameter value using the data of Phase I (but 0 for curvature) to its calibrated value at each year in the order 1) inflation rate, 2) variance of idiosyncratic productivity shocks, 3) curvature of demand, 4) menu cost. Due to the difference between the model estimates and actual values, the sum of the contributions does not equal the actual values.

It is important to note that one reason why implied menu costs increase from Phase I to II and then decrease from Phase II to III is that the joint development of actual frequency and size of price changes over the same set of periods are consistent with such developments in menu costs. On the one hand, as shown in Figure 3, the size of price changes in the service sector modestly increased from Phase I to II and decreased from Phase II to III while the frequency of price changes moved more or less in the opposite direction. On the other hand, as shown in Figure 17, the model predicts that, all else equal, higher menu costs yield a lower frequency of price changes and a larger size of price changes, generating a negative correlation between the two variables. This remains so even if, as suggested in Appendix C, there is some evidence that idiosyncratic variance has increased over time because a higher idiosyncratic variance should result in a higher frequency of price changes and a larger size of price changes if menu costs do not become higher.

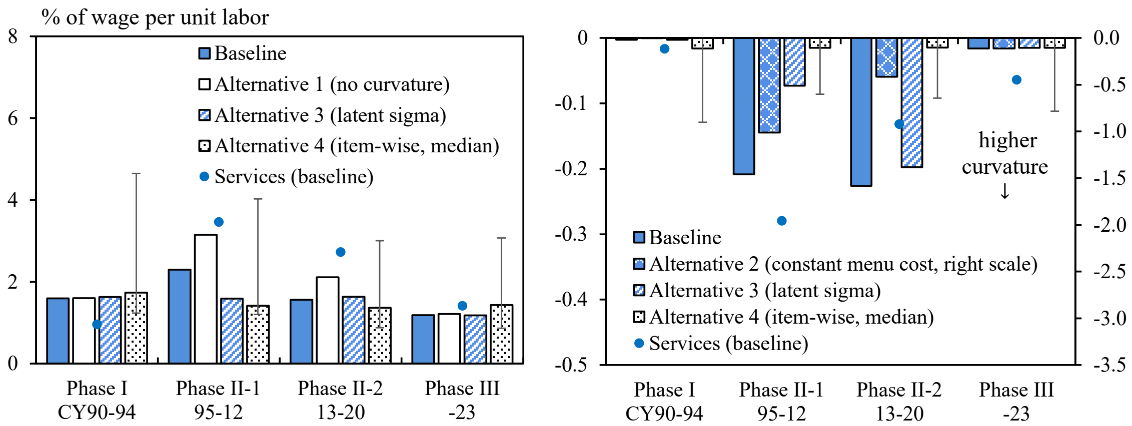
4.2 Discussion on Changes in Model Parameters

In typical menu cost models including our models above, the menu costs are exogenous variables. Our simulation exercises, those shown in Figure 21, therefore simply say that the norm in Japan emerged mostly as an endogenous response to a decline in the inflation rate and a rise in the menu costs and the curvature of the demand curve. By contrast, existing studies on the zero-inflation norm in Japan agree that the norm did not emerge independently from changes in economic environments that occurred after the bubble burst in the early 1990s in particular the decline in the inflation rate. Although we do not provide a model that addresses the theoretical relationship between changes in menu costs and the economic environment, we show some statistical properties of implied menu cost and curvature series obtained above and discuss potential explanations for why these parameters might have changed.

We first document differences in the parameters between service and goods items. Figure 22 shows the developments of implied menu costs and the curvature for the goods sectors estimated in a similar way as those in the service sector. The pattern of increasing menu costs from Phase I to II is observed but only modestly as compared with the service items. Why have menu costs risen saliently in the service sector? Somewhat related to this point, Higo and Saita [2007] document that a fall in the frequency of price changes from the late 1980s and early 1990s to the mid-1990s and early 2000 is pronounced for items that have higher labor costs and argue that the stabilization of wage dynamics during the latter period affected price dynamics of items in an important manner.

(Figure 22) Changes in parameters over time (goods)

Menu cost parameter (K^+) Curvature parameter (η)



Note: The range indicates the 25th to the 75th percentile for the menu cost parameter and the 10th to the 90th percentile for the curvature parameter. The sample period for Phase III is 2023 for the baseline and alternatives 1, 2, and 3, and 2021-2023 for alternative 4.

Indeed, similar results hold for our implied menu costs as well. Table 5 shows the regression results in which the frequency of price changes is included as the dependent variable and labor cost, i.e., expenses for labor inputs divided by all of the expenses for production inputs, is included as the independent variable in the estimation equation. It can be seen that the labor cost explains the frequency of price changes when the pooled sample is used for the estimation. That is, the increase in implied menu costs is higher for items whose costs of production inputs are largely affected by those of labor inputs. This observation also holds when only items in the goods sector are used in the estimation equation. By contrast, the labor cost share is unable to account for differentials in menu costs within the service sector. These observations suggest that while there is the possibility that dynamics of wages play a role in shaping the dynamics of menu costs, there is room for other factors also to play a role in the menu cost dynamics.

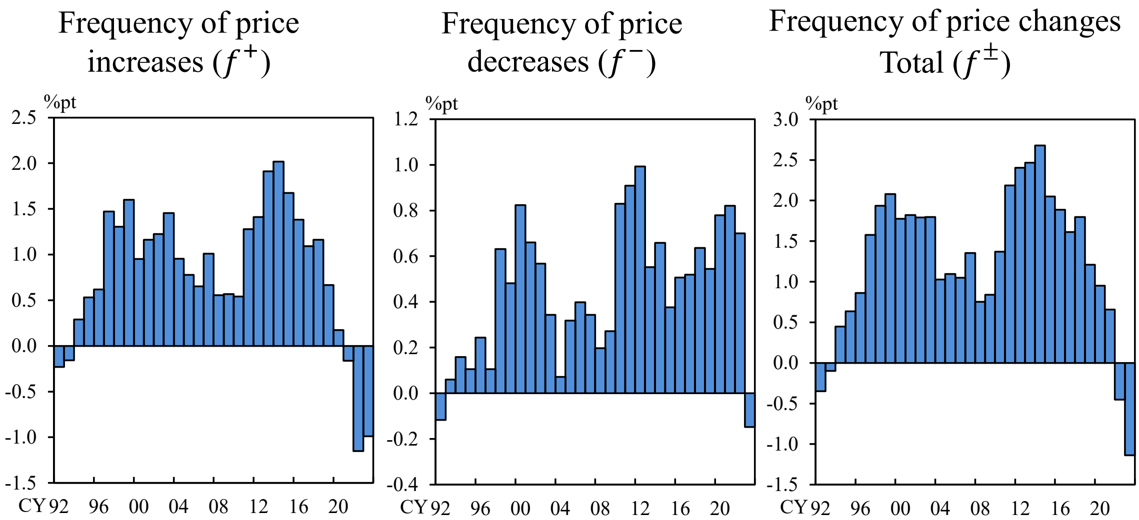
(Table 5) Cross-sectional regression on changes in menu costs

	Dependent variable: Change in menu cost from Phase I to II-1 $D(K^+_{i,\text{II-1}})$			
	All items		Goods	Services
Constant	-1.53	-5.84 **	-4.40 **	-0.08
Share of labor costs	8.76 *	15.19 **	26.78 ***	0.43
Dummy for goods	-	3.48	-	-
Adjusted R^2	0.008	0.013	0.031	-0.020
Observations	282	282	242	40

Notes: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. Shares of Labor costs are calculated from the input table of the 1995 Input-Output Tables.

Next, we study the lagged effect of the inflation rate on menu costs. Uchida [2024], for example, argues that "The mild but persistent deflation created a social norm based on the belief that 'today's prices and wages will be the same tomorrow.' I use the word 'social.' It is not just an economic phenomenon." These arguments imply that the creation of a social norm lags the decline in the inflation rate because households and firms accept the norm only after they see a zero inflation rate prevailing for a prolonged period of time. Indeed, this implication is consistent with the time path of the discrepancy between the model and data for the exercises conducted earlier in this section. Figure 23 shows the time path of the gap between the model and the data regarding the frequency of price changes for the service sector. The gap is limited in the early 1990s and starts to widen markedly from the middle of the 1990s.

(Figure 23) Discrepancy of the frequency of price changes between model and data

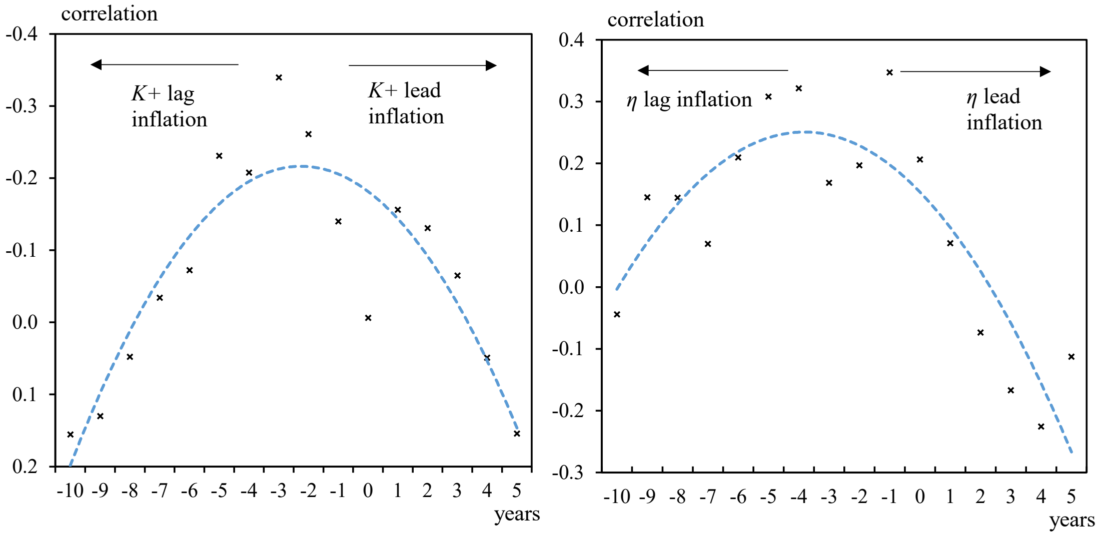


Note: Difference in frequency of price changes between asymmetric menu cost model and actuals in Figure 8.

Figure 24 shows the correlogram between the aggregate inflation rate of the service sector and the time-series of menu costs (K^+) and curvature (η), the parameter that governs the degree of kinkedness, estimated from the baseline approach shown in Table 4. In terms of the timing, both parameters lag the aggregate inflation rate. That is, the menu costs rise and the kinkedness of the demand curve becomes larger three to four years after a decline in the inflation rate. These observations are consistent with the view that the experience of a prolonged period of low inflation and deflation has gradually formed the expectation among households and firms that prices should not be changed, resulting in higher menu costs or a higher degree of competition among firms.

(Figure 24) Cross-correlation with CPI inflation

Menu cost parameter (K^{+}) Curvature parameter (η)



Notes: The parameters are estimates from the baseline approach. Dashed lines are fitted curves with quadratic functions. Excluding outlier (1997).

Table 6 captures the same relationship from a slightly different angle with the cross-section dimension. This time, we use the simulation results computed by alternative approach 4, since this is the only approach that estimates changes in menu costs and the curvature of the demand curve for each item. Using the estimated values, we conduct panel regressions in which the dependent variable is the change in the estimated parameter value and the independent variables include a set of control variables and dummy variables. These dummy variables represent how inflation rates changed from the previous phase. We are interested in whether there is a tendency for menu costs or the curvature parameter to change nonlinearly for an item that sees a fall in the inflation rate to a value below a threshold or a rise of the inflation rate to a value above a threshold in the previous phase.

For changes in menu costs, the coefficient on the dummy variable is positive at a statistically significant level when the state of inflation changes from high to low in the previous phase and negative at a statistically significant level when it changes from low to high state. These results indicate that items that see a decline in the inflation rate below a certain threshold are associated with higher menu costs, and items that see an increase in the inflation rate above a threshold are associated with lower menu costs in the current phase. It is also notable that when dummy variables are included, the coefficient on the change in the inflation rate become insignificant.

(Table 6) Panel estimates of the impact of inflation on the parameters

Dependent Variable Change in parameter values	Explanatory Variable	Coefficients	R^2	
Menu cost: $D(K^{+}_{i,t})$	Change in inflation	-3.70***	0.604	(1)
	State of inflation (t-1 to t)		0.613	(2)
	High to High	-1.1*		
	High to Low	1.6***		
	Low to High	-1.9***		
	Low to Low	-0.0		
	Change in inflation	0.99		
Curvature: $D(\eta_{i,t})$	Change in inflation	0.031***	0.056	(3)
	State of inflation (t-1 to t)		0.053	(4)
	High to High	0.004		
	High to Low	-0.009**		
	Low to High	-0.001		
	Low to Low	0.009***		
	Change in inflation	-0.013		

Notes: Panel regression of individual parameters on inflation and controls. Periods are pooled into 4 phases; Phase I (1990-1994), II-1(1995-2012), II-2(2013-2020), III(2021-2023). State of inflation is a set of dummy variables indicating the change in the level of inflation from the previous period to the current period; High is an average inflation rate of more than 2 percent per year and Low is less than 2 percent per year. For equations 1 and 2, the explanatory variables include a constant, change in idiosyncratic shock of item, and change in curvature of item. For equations 3 and 4, the explanatory variables include a constant, change in idiosyncratic shock of item, and change in menu cost of item. Esimates conducted by EGLS with cross section weights. No fixed effects. R^2 are unweighted. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively.

5 Conclusion

This paper uses the city-level source data of the official CPI in Japan to examine the price-setting behavior of Japanese firms since the 1990s and, in particular, the causes of the emergence of the zero-inflation norm (i.e., the salient decline in firms' frequency of price changes). We first document in detail how the frequency and sizes of price changes have developed over time from the early 1990s to the 2020s. We then construct a set of simple menu cost models, built upon the standard menu cost model of Nakamura and Steinsson [2008], to study two points. Namely, to what extent these models are able to account for the data observations with a decline in the inflation rate and what additional elements are needed to reconcile the model with the data.

Our empirical analysis shows that the emergence of the norm is related to a decline in the inflation rate. The timing of the emergence of the norm roughly coincided with a fall in the aggregate inflation rate that started in the early 1990s and the norm largely disappeared when the aggregate inflation started to increase to a value above zero. Also, items that saw a larger fall in the frequency of price changes are those that saw a larger fall in their respective inflation rates during the period when the norm prevailed. The norm is related to the size and the asymmetry of upward and downward changes in the frequency of price changes. Both in the aggregate and at the item level, a fall in the frequency of price changes occurred because the frequency of price increases fell noticeably while the frequency of price decreases did not rise much.

The first part of our model exercise shows that about half of the emergence of the norm is explained by the model that takes a decline in the trend inflation rate as an input. While this exercise indicates that the emergence of the norm agrees to some extent with the prediction of the standard model, it also underscores the importance of the characteristics of menu costs in price dynamics. When menu costs are set in a way consistent with the U.S. economy, for example, the model predicts that the frequency of price changes does not react much to a decline in the inflation rate, as suggested by Alvarez *et al*. (2019). By contrast, the model predicts the emergence of the norm to some extent when menu costs are calibrated to be consistent with price dynamics in Japan for the period before the norm emerged. The values of these menu costs are larger than those of the U.S. and asymmetric in the sense that menu costs for downward price changes are larger than those for upward price changes. These menu costs cause firms to become less active in changing prices when the inflation rate falls. The second part of our model exercise shows that there might have been changes in model parameters, in particular, a rise in menu costs, during the period when the norm emerged. Clearly, firms become inactive in terms of price changes when it is more costly to change their prices. Increases in implied menu costs are noticeably seen items in the service sector and less in the goods sector. Furthermore, they lag a fall in the inflation rate and are pronounced in the service items that saw a decline in the inflation rate to a value close to zero in the latter half of the 1990s, suggesting the possibility that there have been interplays between the inflation rate and the menu cost that the standard menu cost models do not predict.

Characteristics of implied menu costs over the phases and across items somehow indicate what "menu costs" represent in practice may not be the costs of physically renewing the menus. Alternative candidate explanations for example include managerial costs of changing list prices stressed for example by Zbaracki *et al.* [2004] and others or concerns about the fairness of pricing stressed by Rotemberg [2011]. Indeed, motivated by the findings documented by Zbaracki *et al.* [2004], Midrigan [2011] shows, using a multi-product menu cost model, that the smaller the number of products for which firms revise prices simultaneously, the larger the menu cost per product revision becomes due to the existence of scale effects, making price revisions less likely.

We have two reservations regarding our results. First, our work focuses on why the zero-inflation norm emerged in the mid-1990s in Japan. This question is closely related to, but differs from, questions such as why the inflation rate in Japan did not increase much during the period when the norm was prevalent, since our model analysis takes the time path of the aggregate and individual inflation rates as given and focuses on how these inflation rates can account for developments in the intensive and extensive margin of price dynamics. In order to address the latter type of question, not only price dynamics but also the dynamics of input prices, including wages, and the interaction between output and input price dynamics should be analyzed.[18] Second, while our model exercises imply that there is a quantitative relationship between the level of the inflation rate and the size of menu costs and/or the degree of kinkedness of the demand curve, the analyses do not fully uncover the relationships among them, including the directions of causality. These questions are particularly important when considering if similar zero-inflation norms could arise in other countries or other periods, or in what kind of economic circumstances. Exploring price dynamics in Japan further in these areas is left to future research.

[18] For example, Aoki, Hogen, and Takatomi [2023] and Aoki *et al*. [2024] document that in Japan, while price markups have been shrinking over the years, possibly due to the competitive environment, firms have been increasing their profits by expanding their wage markdowns.

References

[1] Abe, N. and A. Tonogi (2010), "Micro and Macro Price Dynamics in Daily Data," *Journal of Monetary Economics*, 57(6), 716-728.

[2] Alvarez, F., M. Beraja, M. Gonzalez-Rozada, and P. A. Neumeyer (2019), "From Hyperinflation to Stable Prices: Argentina's Evidence on Menu Cost Models," *The Quarterly Journal of Economics*, 134(1), 451-505.

[3] Aoki, K., Y. Hogen, Y. Ito, K. Kanai, and K. Takatomi (2024), "Determinants of Price Markups of Japanese Firms and Implications for Productivity," forthcoming, Bank of Japan.

[4] Aoki, K., Y. Hogen, and K. Takatomi (2023), "Price Markups and Wage Setting Behavior of Japanese Firms," Bank of Japan Working Paper Series, No.23-E-5.

[5] Aoki, K., H. Ichiue and T. Okuda (2019), "Consumers' Price Beliefs, Central Bank Communication, and Inflation Dynamics," Bank of Japan Working Paper Series, No.19-E-14.

[6] Bank of Japan (2021), Assessment for Further Effective and Sustainable Monetary Easing.

[7] Bank of Japan (2024), "*Results of the Survey regarding Corporate Behavior since the Mid-1990s,*" Regional Economic Report Annex.

[8] Bils, M. and P. J. Klenow (2004), "Some Evidence on the Importance of Sticky Prices," *Journal of Political Economy*, 112(5), 947-985.

[9] Blanco, A., C. Boar, C. J. Jones, and V. Midrigan (2024), "Non-Linear Inflation Dynamics in Menu Cost Economies", NBER Working Paper, No. 32094.

[10] Dhyne, E., L. J. Alvarez, H. L. Bihan, G. Veronese, D. Dias, J. Hoffmann, N. Jonker P. Lünnemann, F. Rumler, and J. Vilmunen (2006), "Price Changes in the Euro Area and the United States: Some Facts from Individual Consumer Price Data," *Journal of Economic Perspectives*, 20(2), 171-192.

[11] Fukunaga, I., Y. Kido, and K. Suita (2024), "Japan's Inflation under Global Inflation Synchronization," Bank of Japan Working Paper Series, No. 24-E-4.

[12] Furukawa, K., Y. Hogen, and K. Otaka (2024), "On Price Setting and the Zero-Inflation Norm of Japanese Firms," Bank of Japan Working Paper Series, No. 24-J-18 (in Japanese).

[13] Gautier, E., P. Karadi, J. Amann, C. Conflitti, R. Faber, B. Fabo, L. Fadejava, *et al*. (2023), "Price Adjustment in the Euro Area in the Low-Inflation Period: Evidence from Consumer and Producer Micro Price Data," ECB Occasional Paper, No. 2023/319.

[14] Golosov, M. and R. E. Lucas Jr. (2007), "Menu Costs and Phillips Curves," *Journal of Political Economy*, 115(2), 171-199.

[15] Higo, M. and Y. Saita (2007), "Price Setting in Japan: Evidence from CPI Micro Data," Bank of Japan Working Paper Series, No.07-E-20.

[16] Ichiue, H., Y. Uno, T. Okuda, T. Fueki, and K. Maehashi (2019), "Recent Issues about Inflation Dynamics: Japan's Experience," Bank of Japan Working Paper Series, No. 19-J-3 (in Japanese).

[17] Ikeda, D. and S. Nishioka (2007), "Price Setting Behavior and Hazard Functions: Evidence from Japanese CPI Micro Data," Bank of Japan Working Paper Series, No.07-E-19.

[18] Kaihatsu, S., M. Katagiri, and N. Shiraki (2022), "Phillips Correlation and Price-Change Distributions under Declining Trend Inflation," *Journal of Money, Credit and Banking*, 55(5), 1271-1305.

[19] Karadi, P. and A. Reiff (2019), "Menu Costs, Aggregate Fluctuations, and Large Shocks," *American Economic Journal: Macroeconomics*, 11(3), 111-146.

[20] Kehoe, P. and V. Midrigan (2015), "Prices are Sticky after All," *Journal of Monetary Economics*, 75, 35-53.

[21] Kimball, M. S. (1995), "The Quantitative Analytics of the Basic Neomonetarist Model," *Journal of Money, Credit and Banking*, 27(4), 1241-1277.

[22] Klenow, P. J. and O. Kryvtsov (2008), "State-Dependent or Time-Dependent Pricing: Does It Matter for Recent U.S. Inflation?," *The Quarterly Journal of Economics*, 123(3), 863-904.

[23] Kurachi, Y., K. Hiraki, and S. Nishioka (2016), "Does a Higher Frequency of Micro-level Price Changes Matter for Macro Price Stickiness? Assessing the Impact of Temporary Price Changes," Bank of Japan Working Paper Series, No.16-E-9.

[24] Kuroda, H. (2022a), *The Bank's Thinking on Monetary Policy: Toward Achieving the Price Stability Target in a Sustainable and Stable Manner*, Bank of Japan,

https://www.boj.or.jp/en/about/press/koen_2022/data/ko220606a1.pdf.

[25] Kuroda, H. (2022b), *Toward Achieving the Price Stability Target in a Sustainable and Stable Manner, Accompanied by Wage Increases*, Bank of Japan, https://www.boj.or.jp/en/about/press/koen_2022/data/ko221226a1.pdf.

[26] Kuroda, S. and I. Yamamoto (2003), "Are Japanese Nominal Wages Downwardly Rigid? (Part I): Examinations of Nominal Wage Change Distributions," *Monetary and Economic Studies*, Institute for Monetary and Economic Studies, Bank of Japan, vol. 21(2), 1-29.

[27] Levin, A. T., J. D. López-Salido, and T. Yun (2007), "Strategic Complementarities and Optimal Monetary Policy," Kiel Working Papers, 1355.

[28] Michaelis, H. and S. Watzka (2017), "Are There Differences in the Effectiveness of Quantitative Easing at the Zero-Lower-Bound in Japan over Time?," *Journal of International Money and Finance*, 70, 204-233.

[29] Midrigan, V. (2011), "Menu Costs, Multiproduct Firms, and Aggregate Fluctuations," *Econometrica*, 79(4), 1139-1180.

[30] Mizuno, T., M. Nirei, and T. Watanabe (2010), "Closely Competing Firms and Price Adjustment: Some Findings from an Online Marketplace," *The Scandinavian Journal of Economics*, 112(4), 673-696.

[31] Nakamura, E. and J. Steinsson (2008), "Five Facts about Prices: A Reevaluation of Menu Cost Models," *The Quarterly Journal of Economics*, 123(4), 1415-1464.

[32] Nakamura, E. and J. Steinsson (2010), "More Facts about Prices," Columbia University, https://eml.berkeley.edu/˜jsteinsson/papers/fivefactssupplement.pdf. Accessed July 18, 2023.

[33] Nishizaki, K., T. Sekine, and Y. Ueno (2014), "Chronic Deflation in Japan," *Asian Economic Policy Review*, 9(1), 20-39.

[34] Okun, A. M. (1981), *Prices and Quantities: A Macroeconomic Analysis*, Brookings Institution Press.

[35] Rotemberg, J. J. (2011), "Fair Pricing," *Journal of the European Economic Association*, 9(5), 952-981.

[36] Schultze, C. L. (1981), "Some Macro Foundations for Micro Theory," *Brookings Papers on Economic Activity*, 1981(2), 521-592.

[37] Sudo, N., K. Ueda, and K. Watanabe (2014), "Micro Price Dynamics during Japan's Lost Decades," *Asian Economic Policy Review*, 9(1), 44-64.

[38] Tauchen, G. (1986), "Finite State Markov-Chain Approximation to Univariate and Vector Autoregressions," *Economics Letters*, 20(2), 177-181.

[39] Ueda, K. (2024), "Evidence on Price Stickiness in Japan," *The Japanese Economic Review*, https://doi.org/10.1007/s42973-024-00161-w.

[40] Uchida, S. (2024), "Price Dynamics in Japan over the Past 25 Years," Keynote Speech at the 2024 BOJ-IMES Conference Hosted by the Institute for Monetary and Economic Studies, Bank of Japan.

[41] Watanabe, T. (2023), "Price Rigidity in Japan," in *Price Dynamics in Goods and Asset Markets*, edited by T. Watanabe and C. Shimizu, University of Tokyo Press (in Japanese).

[42] Watanabe, K. and T. Watanabe (2018), "Why Has Japan Failed to Escape from Deflation?" *Asian Economic Policy Review*, 13(1), 23-41.

[43] Zbaracki, M. J., M. Ritson, D. Levy, S. Dutta, and M. Bergen (2004), "Managerial and Customer Costs of Price Adjustment: Direct Evidence from Industrial Markets," *The Review of Economics and Statistics*, 86(2), 514-533.

Appendix A: Data

This appendix describes the details of the data we use for our analysis.

(The main data)

The key data source of our analysis is the city-level data in the *Retail Price Survey* that includes monthly average prices by item and city. This series has been used in many previous studies of price dynamics in Japan, such as Higo and Saita [2007] and Kurachi, Hiraki, and Nishioka [2016]. We measure the frequency and size of price changes as follows. First, the item-specific frequency of price changes is calculated as the percentage of cities where the average price changed from the previous month. Second, the size of price change is calculated as the average rate of change in cities where the price changed from the previous month. The macro frequency and the size of price changes are then calculated as a weighted average of the CPI weights for each item. In this process, we exclude items that are not surveyed in each city (e.g., nationally standardized items), seasonal items, and months of specific items where the basis for the price survey has changed from the previous month.[19]

There are several things to note about the above method. First, the level of the frequency of price changes may depend on the number of stores surveyed in each city. For example, if the number of stores surveyed in a city is large, the frequency of price changes is likely to be higher, since a price revision in one of these stores will change the average price in the entire city. To reduce this bias due to the number of surveyed stores, this paper follows Higo and Saita [2007] and uses only data from medium-sized cities[20] where the number of surveyed stores is almost the same. The average number of stores surveyed for each item is about 3 stores. Second, the city-level data do not include the price level of individual stores, so the frequency and size of price changes may differ from store-level data. This could lead to a potential bias in the frequency of price changes because it is not possible to distinguish changes in average prices when the stores surveyed change or the number of stores in the survey change.

(Comparison with the data constructed from store-level data)

Figure A1-1 shows a comparison of the frequency of price changes measured by city-level data and store-level data. Note that the latter series is taken from Furukawa, Hogen,

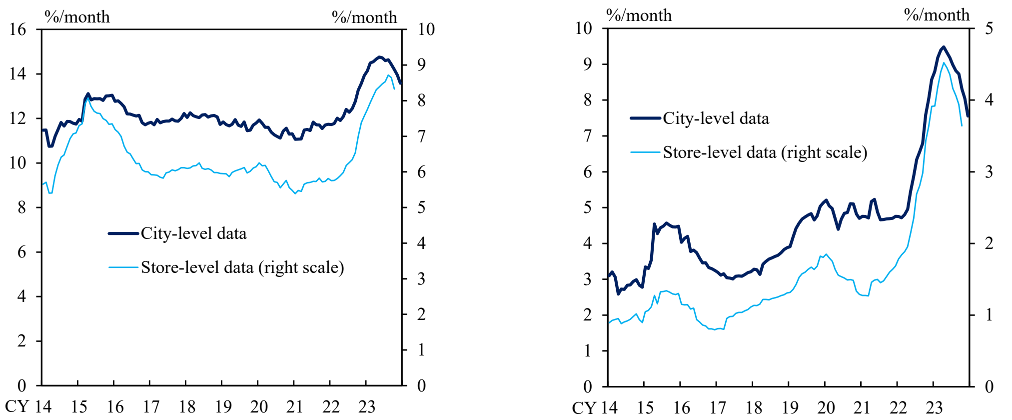
[19] A detailed guideline is administered by the Ministry of Internal Affairs and Communications for which prices to collect for each good and service. The guideline is revised on a necessary basis for major goods and services sold nationwide, with less variety in quality and function.

[20] Cities that have populations larger than 150 thousand people (excluding ordinance designated city).

and Otaka [2024]. Generally speaking, the series show similar patterns.[21]

(Figure A1-1) Frequency of price changes

Goods Services



Note: The data exclude fresh food, electricity, manufactured and piped gas, water charges, housing rent, periods of consumption tax hikes and temporary price changes mainly due to special sales (same for the following figures). Backward 12-month moving average.

Source: Ministry of Internal Affairs and Communications.

(Sales filters)

Temporary price fluctuations due to special sales, etc. are adjusted for in many studies that use "regular prices" when comparing the frequency and size of price change (Kehoe and Midrigan [2015], Nakamura and Steinsson [2008], Kurachi, Hiraki, and Nishioka [2016]).[22] Since the data used in this paper do not contain information on whether the price is a special price or not, we compute regular prices using the algorithm proposed in previous studies.[23] Specifically, we use the Running Mode filter proposed by Kehoe and Midrigan [2015] and the V-Shaped filter proposed by Nakamura and Steinsson [2008]. The V-Shaped filter is a method that considers price fluctuations that return to the original level after the price falls as temporary price fluctuations. In this paper, we basically use the Running Mode filter to adjust for temporary fluctuations (Sudo, Ueda, and Watanabe [2014] and Kurachi, Hiraki, and Nishioka [2016]).

[21] Time series changes in the size of price changes are similar for both sources as well.

[22] Kurachi, Hiraki, and Nishioka [2016] show that the impact from temporary sales only has a modest effect on aggregate inflation. Therefore changes in regular prices are more important in Japan.

[23] CPI excludes special sales with duration of 7 days or less, but could still include sales with longer duration.

Appendix B: Analysis using a Simple Static Model

(Setting for profit function)

For illustrative purpose, in this appendix, we derive implications to the frequency of price changes of change in the key model parameters such as trend inflation rate using a simple static model. Suppose that the demand of a firm is given by $f(p)$, where p is the relative price of the firm, and that the marginal cost of production is constant at c. Then the firm's profit is given by:

$$\Pi(p;c) = pf(p) - f(p)c \tag{A2\_1}$$

Its partial derivative with respect to the price is

$$\begin{aligned}\frac{\partial \Pi(p;c)}{\partial p} &= f(p) + pf'(p) - f'(p)c \\ &= f'(p)\left(p + \frac{f(p)}{f'(p)} - c\right) \\ &= f'(p)\left(\left(1 - \frac{1}{\varepsilon(p)}\right)p - c\right) \\ &= \frac{f'(p)}{\mu(p)}(p - \mu(p)c)\end{aligned} \tag{A2\_2}$$

where

$$\varepsilon(p) \equiv -\frac{df/f}{dp/p} \tag{A2\_3}$$

is the price elasticity of demand and

$$\mu(p) \equiv \frac{\varepsilon(p)}{\varepsilon(p) - 1} \tag{A2\_4}$$

is the markup. Thus, the profit maximizing price p^* satisfies:

$$p^* = \mu(p^*)c \tag{A2\_5}$$

Totally differentiating equation (A2_5), we obtain

$$\frac{dp^*}{p^*} = \frac{\mu'}{\mu}p^*\frac{dp^*}{p^*} + \frac{dc}{c} \tag{A2\_6}$$

$$\therefore \frac{dp^*/p^*}{dc/c} = \frac{1}{1+\tilde{\eta}} \tag{A2\_7}$$

where

$$\tilde{\eta} \equiv -\frac{d\mu/\mu}{dp^*/p^*} \tag{A2\_8}$$

is the price elasticity of markup. Note that $\tilde{\eta} > 0$ and a larger $\tilde{\eta}$ implies a higher curvature of the demand curve.

(Inaction region without trend inflation)

Suppose that the marginal cost of production is initially c_0 and the price is set at the profit maximizing level p_0^*. When the marginal cost changes from c_0 to c_1, the firm changes the price to the corresponding profit maximizing p_1^* if by doing so the firm's profit increases by more than the menu cost Φ. That is, the firm changes the price if

$$\Pi(p_1^*; c_1) - \Pi(p_0^*; c_1) > \Phi \qquad \text{(A2\_9)}$$

The Taylor expansion of $\Pi(p; c)$ around (p_0^*, c_0) up to the second degree yields

$$\begin{aligned}\Pi(p; c) = \Pi(p_0^*; c_0) &+ \frac{\partial \Pi}{\partial p}(p_0^*; c_0)(p - p_0^*) + \frac{\partial \Pi}{\partial c}(p_0^*; c_0)(c - c_0) \\ &+ \frac{1}{2}\left\{\frac{\partial^2 \Pi}{\partial p^2}(p_0^*; c_0)(p - p_0^*)^2 \right. \\ &\left. + 2\frac{\partial^2 \Pi}{\partial p \partial c}(p_0^*; c_0)(p - p_0^*)(c - c_0) + \frac{\partial^2 \Pi}{\partial c^2}(p_0^*; c_0)(c - c_0)^2\right\}\end{aligned} \qquad \text{(A2\_10)}$$

Since p_0^* is profit maximizing given c_0, we have $\partial \Pi / \partial p = 0$. Moreover, by equation (A2_1), we also have $\partial \Pi / \partial c = -f(p)$ and $\partial^2 \Pi / \partial c^2 = 0$. By differentiating equation (A2_2) with respect to p, we obtain

$$\begin{aligned}\frac{\partial^2 \Pi}{\partial p^2}(p_0^*; c_0) &= \frac{\partial}{\partial p}\left(\frac{f'(p)}{\mu(p)}\right) \cdot \left(\frac{p_0^*}{\mu(p_0^*)} - c_0\right) + \frac{f'(p_0^*)}{\mu(p_0^*)}(1 - \mu'(p_0^*)c_0) \\ &= \frac{f'(p_0^*)}{p_0^*}\left(\frac{p_0^*}{\mu(p_0^*)} - \frac{\mu'(p_0^*)p_0^*}{\mu(p_0^*)}c_0\right) \\ &= \frac{f'(p_0^*)}{p_0^*}(c_0 + \tilde{\eta}c_0) \\ &= \frac{f'(p_0^*)}{p_0^*}(1 + \tilde{\eta})c_0\end{aligned} \qquad \text{(A2\_11)}$$

where we make use of equation (A2_5) and equation (A2_8). Thus, we can rewrite equation (A2_10) as

$$\begin{aligned}\Pi(p; c) &= \Pi(p_0^*; c_0) - f(p_0^*)(c - c_0) \\ &\quad + \frac{1}{2}\left\{\frac{f'(p_0^*)}{p_0^*}(1 + \tilde{\eta})c_0(p - p_0^*)^2 \right. \\ &\quad \left. - 2f'(p_0^*)(p - p_0^*)(c - c_0)\right\} \\ &= \Pi(p_0^*; c_0) - f(p_0^*)(c - c_0) \\ &\quad - \frac{f(p_0^*)\varepsilon}{2}\left(\frac{p - p_0^*}{p_0^*}\right)\left\{(1 + \tilde{\eta})c_0\left(\frac{p - p_0^*}{p_0^*}\right) \right. \\ &\quad \left. - 2(c - c_0)\right\}\end{aligned} \qquad \text{(A2\_12)}$$

where we make use of equation (A2_3). If $c_1 - c_0$ is small, we can write $(p_1^* - p_0^*)/p_0^*$ as $(c_1 - c_0)/(c_0(1 + \eta))$ from equation (A2_7). Then, from equation (A2_12), we have

$$\Pi(p_1^*; c_1) = \Pi(p_0^*; c_0) - f(p_0^*)(c_1 - c_0) + \frac{1}{2}\frac{f(p_0^*)\varepsilon}{1 + \tilde{\eta}}c_0\left(\frac{c_1 - c_0}{c_0}\right)^2 \qquad \text{(A2\_13)}$$

Since $\pi(p_0^*; c_1) = \pi(p_0^*; c_0) - f(p_0^*)(c_1 - c_0)$ up to the second degree of approximation, we obtain

$$\Pi(p_1^*;c_1) - \Pi(p_0^*;c_1) = \frac{1}{2}\frac{f(p_0^*)\varepsilon}{1+\tilde{\eta}}c_0\left(\frac{c_1-c_0}{c_0}\right)^2 \tag{A2\_14}$$

Thus, equation (A2_9) implies the firm changes the price if

$$\left|\frac{c-c_0}{c_0}\right| > \sqrt{\frac{2(1+\tilde{\eta})\Phi}{\varepsilon f(p_0^*)c_0}} \tag{A2\_15}$$

(Role of trend inflation rate)

Let us now consider the case where trend inflation rate π is greater than zero. In this case, the firm's relative price changes from p_0^* to $(1-\pi)p_0^*$ in period one if it chooses not to reset the price from period zero to one. Thus, the firm's price decision problem equation (A2_9) becomes

$$\Pi(p_1^*;c_1) - \Pi((1-\pi)p_0^*;c_1) > \Phi \tag{A2\_16}$$

From equation (A2_12), we have

$$\begin{aligned}\Pi((1-\pi)p_0^*;c_1)& \\ &= \Pi(p_0^*;c_0) - f(p_0^*)(c_1-c_0) \\ &-\frac{1}{2}\{f(p_0^*)\varepsilon(1+\tilde{\eta})c_0\pi^2 + 2f(p_0^*)\varepsilon\pi(c_1-c_0)\}\end{aligned} \tag{A2\_17}$$

Hence,

$$\begin{aligned}\Pi(p_1^*;c_1) - \Pi((1-\pi)p_0^*;c_1)& \\ &= \frac{1}{2}\frac{f(p_0^*)\varepsilon}{1+\tilde{\eta}}c_0\left(\frac{c_1-c_0}{c_0}\right)^2 \\ &\qquad + \frac{1}{2}\{f(p_0^*)\varepsilon(1+\tilde{\eta})c_0\pi^2 + 2f(p_0^*)\varepsilon\pi(c_1-c_0)\} \\ &= \frac{1}{2}\frac{f(p_0^*)\varepsilon}{1+\tilde{\eta}}c_0\left(\frac{c_1-c_0}{c_0} + (1+\tilde{\eta})\pi\right)^2\end{aligned} \tag{A2\_18}$$

Thus, the condition (A2_16) leads to

$$-(1+\tilde{\eta})\pi - \sqrt{\frac{2(1+\tilde{\eta})\Phi}{\varepsilon f(p_0^*)c_0}} < \frac{c-c_0}{c_0} < -(1+\tilde{\eta})\pi + \sqrt{\frac{2(1+\tilde{\eta})\Phi}{\varepsilon f(p_0^*)c_0}} \tag{A2\_19}$$

To simplify the notation, let us denote

$$\overline{c} \equiv -(1+\tilde{\eta})\pi + \sqrt{\frac{2(1+\tilde{\eta})\Phi}{\varepsilon f(p_0^*)c_0}} \tag{A2\_20}$$

$$\underline{c} \equiv -(1+\tilde{\eta})\pi - \sqrt{\frac{2(1+\tilde{\eta})\Phi}{\varepsilon f(p_0^*)c_0}} \tag{A2\_21}$$

To see what the model implies for the frequency of price changes, let $F(\cdot)$ denote the cumulative distribution function of the marginal cost shock that occurs at the period one $(c-c_0)/c_0$. Then, the frequency of price changes $freq$ is given by

$$freq = F(\underline{c}) + 1 - F(\overline{c}) \tag{A2\_22}$$

Its derivative with respect to the trend inflation rate π is

$$\frac{\partial freq}{\partial \pi} = (1+\tilde{\eta})\left(f(\overline{c}) - f(\underline{c})\right) \tag{A2\_23}$$

where $f(\cdot)$ denotes the probability distribution function of the marginal cost shock.

To simplify the discussion, we make a few assumptions about $f(x)$. The first assumption is that it is symmetric around zero so that $f(x) = f(-x)$. Second, it is monotonically decreasing when $x \geq 0$. By the first assumption, it implies that $f(x)$ is monotonically increasing when $x \leq 0$. This second assumption means that as a shock becomes larger in absolute terms the probability of that a marginal cost shock takes that value falls. The third assumption is that $f(x)$ is differentiable.

These assumptions imply that $\partial freq/\partial\pi = 0$ when $\pi = 0$ as $\overline{c} = \underline{c}$. Moreover, if the trend inflation rate is not significantly different from zero so that $\overline{c} > 0$ and $\underline{c} < 0$, then we have $\partial^2 freq/\partial\pi^2 > 0$ since $f(\overline{c}) - f(\underline{c})$ is increasing with respect to π. Thus, the frequency of price changes is convex with respect to trend inflation.

The above discussion indicates that $\partial freq/\partial\pi$ is close to zero when π is sufficiently small. In other words, the frequency of price changes does not depend on a value of the trend inflation rate when the trend inflation is small.

(Role of asymmetry in menu costs)

It is straightforward to generalize this argument to the case where the menu cost is asymmetric. Suppose the firm incurs the menu cost Φ_+ when it increases the price and Φ_- when it decreases the price. Then, the firm increases the price if

$$-(1+\tilde{\eta})\pi + \sqrt{\frac{2(1+\tilde{\eta})\Phi_+}{\varepsilon f(p_0^*)c_0}} < \frac{c - c_0}{c_0} \tag{A2\_24}$$

and decreases the price if

$$\frac{c - c_0}{c_0} < -(1+\tilde{\eta})\pi - \sqrt{\frac{2(1+\tilde{\eta})\Phi_-}{\varepsilon f(p_0^*)c_0}} \tag{A2\_25}$$

In this setting, Equations (A2_20) and (A2_21) above are rewritten as:

$$\overline{c} = -(1+\tilde{\eta})\pi + \sqrt{\frac{2(1+\tilde{\eta})\Phi_+}{\varepsilon f(p_0^*)c_0}} \tag{A2\_26}$$

$$\underline{c} = -(1+\tilde{\eta})\pi - \sqrt{\frac{2(1+\tilde{\eta})\Phi_-}{\varepsilon f(p_0^*)c_0}} \tag{A2\_27}$$

Differentiating equation (A2_22) with respect to the menu cost parameters Φ_+ and Φ_- gives

$$\frac{\partial freq}{\partial \Phi_+} = -\sqrt{\frac{1+\tilde{\eta}}{2\varepsilon f(p_0^*)c_0\Phi_+}} f(\overline{c}) \tag{A2_28}$$

$$\frac{\partial freq}{\partial \Phi_-} = -\sqrt{\frac{1+\tilde{\eta}}{2\varepsilon f(p_0^*)c_0\Phi_-}} f(\underline{c}) \tag{A2_29}$$

Therefore, higher menu costs lead to lower frequency of price changes.

The asymmetry of menu costs also affects how the frequency of price changes responds to the trend inflation rate. When the trend inflation is positive and $\Phi_- > \Phi_+$, it is evident from equation (A2_26) and (A2_27) that $|\underline{c}| > |\overline{c}|$. Then, the above assumptions on $f(x)$ implies that $f(\underline{c}) < f(\overline{c})$. In this case, equation (A2_23) indicates that the frequency of price changes increases as the trend inflation rises. Moreover, given the shape of $f(\cdot)$ is fixed, more asymmetric menu costs (i.e., larger relative size of Φ_- with respect to Φ_+) leads to a greater value of $f(\overline{c}) - f(\underline{c})$, making the frequency of price changes more sensitive to changes in the trend inflation.

(Role of curvature)

Next, we consider how the curvature of the demand curve affects the frequency of price changes. Let us assume for simplicity that menu costs are symmetric, i.e., $\Phi_+ = \Phi_- = \Phi$. Differentiating equation (A2_22) with respect to the curvature parameter $\tilde{\eta}$ gives

$$\begin{aligned}\frac{\partial freq}{\partial \tilde{\eta}} &= \left(-\pi - \sqrt{\frac{\Phi}{\varepsilon(1+\tilde{\eta})f(p_0^*)c_0}}\right) f(\underline{c}) \\ &\qquad - \left(-\pi + \sqrt{\frac{\Phi}{\varepsilon(1+\tilde{\eta})f(p_0^*)c_0}}\right) f(\overline{c}) \\ &= \pi\left(f(\overline{c}) - f(\underline{c})\right) - \sqrt{\frac{\Phi}{\varepsilon(1+\tilde{\eta})f(p_0^*)c_0}}\left(f(\overline{c}) + f(\underline{c})\right)\end{aligned} \tag{A2_30}$$

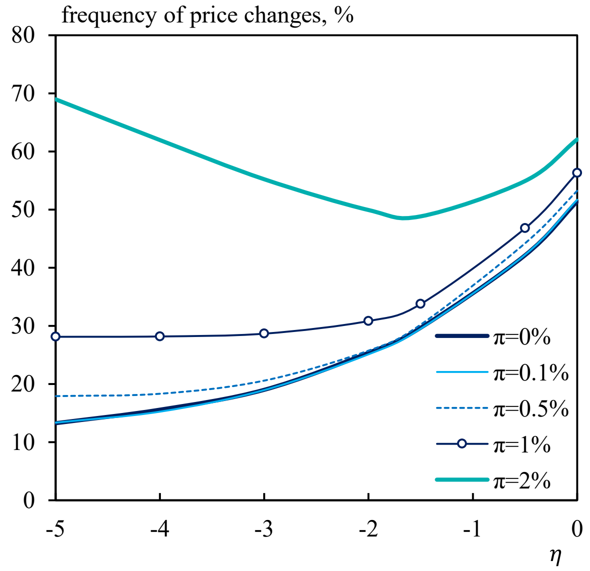
Equation (A2_30) implies the following: First, when the trend inflation rate is zero ($\pi = 0$), $\partial freq/\partial \tilde{\eta}$ is always negative. Second, if the trend inflation rate is positive, it is possible that $\partial freq/\partial \tilde{\eta} > 0$. In other words, the relationship between the curvature of the demand curve and the frequency of price changes can depend on the level of trend inflation.

To illustrate this point, we run a simple numerical simulation. Here, we assume the Kimball-type quasi-kinked demand curve (Kimball [1995])

$$f(p) = \frac{1}{1+\eta}\left(p^{-\epsilon(1+\eta)} + \eta\right) \tag{A2_31}$$

where $\eta \leq 0$ and a larger value of $|\eta|$ indicates a higher curvature of the demand curve.[24] We set the parameter values $(\epsilon, c_0, \Phi) = (20{,}0.95{,}0.01)$. In this case, $p_0^* = 1$ regardless of the value of η. We further assume that the shock to the marginal cost, $(c_1 - c_0)/c_0$, follows a normal distribution $N(0, 0.05^2)$. For given values of the remaining parameters (η, π) and a randomly generated c_1, we numerically solve the firm's price setting problem equation (A2_16). We repeat this exercise 100,000 times and calculate the frequency of price changes. The following figure shows the result:

(Figure A2-1) Relationship between the curvature of the demand curve and the frequency of price changes (static model)



We can observe that while the frequency of price changes monotonically decreases as $|\eta|$ increases when $\pi = 0$, it actually starts increasing once $|\eta|$ becomes large enough when there is a positive trend inflation.

(Role of variance)

Lastly, we consider how the variance of marginal cost shocks affect the frequency of price changes. Suppose that the variance of marginal cost shocks increases, indicating that larger shocks are more likely to occur. The simplest way to express this change mathematically is to assume that $F(\underline{c})$ becomes larger for a given $\underline{c}$ and that $F(\overline{c})$ becomes smaller for a given $\overline{c}$. It is evident from equation (A2_22) that the frequency of price changes consequently increase.

---

[24] The price elasticity of demand is constant when $\eta = 0$ and the demand curve becomes more concave as η becomes more negative.

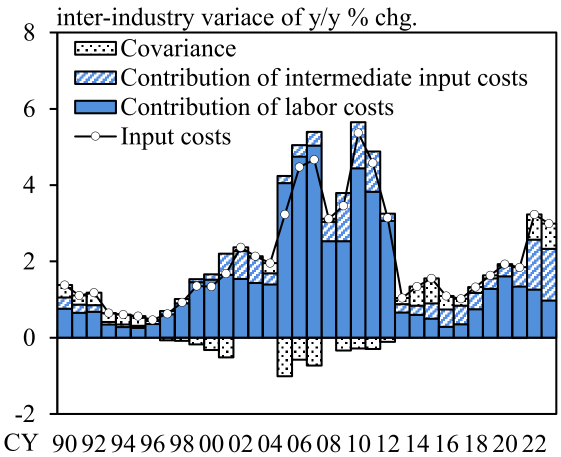
Appendix C: Constructing Idiosyncratic Variation

In Section 4, we execute simulations exercises to quantify potential changes in the model's key parameters, including the variance of idiosyncratic productivity σ_ε^2. In the simulations of alternatives 3 and 4, we assume that the variance is not directly observable and estimate the time path of the variance from the data of the frequency and size of price changes. In the baseline and alternatives 1 and 2, by contrast, we assume that the variance is observable, feed through the time series of the variance into the model and estimate changes in other parameters.

In this Appendix, we explain how we construct the proxy variable for the variance σ_ε^2 which we use as the observable of the variance in the simulations of the baseline and alternatives 1 and 2. We first construct this time series of the annual growth of input cost for each industry in the service sector by aggregating the growth of labor compensation in the SNA statistics and the growth of the intermediate input deflator using input cost weights. We then compute the variance of the input cost growth across industries.

Figure A3-1 shows the time path of this series. It has been trending upward since the early 1990s until around 2010, possibly due to the changes in the way that annual wage negotiations are made, and has been trending downward since then. In most of the sample period, the bulk of the variations in the series has been brought about by variations in the contributions of labor costs. For example, one reason why the variance went up during Phase II-1 (1995-2012) is that some industries, such as hotels and food accommodation services, saw a large labor cost declines due to relatively large increases in the share of part-time workers while the rest of the industries did not.

(Figure A3-1) Inter-industry variation of input cost growth (service sectors)



Notes: Figures are 3-year backward moving averages. Input costs are weighted averages of compensation per employee and input deflators, with nominal inputs as weights. Values for 2023 are extended estimates based on monthly statistics.
Sources: Cabinet Office; Cabinet Secretariat; Ministry of Health, Labour and Welfare; Bank of Japan.